Interpretation of airborne gravity gradiometry and magnetic data using cross-gradients

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SUMMARY

Computing the cross-gradient product of airborne vertical gravity and magnetic intensity data provides a means to combine information about two different physical properties into the same image, thereby aiding interpretation. The method utilises the angle and cross-product values between the horizontal gradients of each dataset to produce two images in which structural similarities are enhanced.

The theoretical basis for the method and results of its application to the survey data are discussed.

The cross-gradient method was tested on a synthetic model and applied to FALCON™ airborne gravity gradiometer data from the Halls Creek Orogen, Western Australia. The vertical component of the gravity vector and the reduced to magnetic pole total magnetic intensity, were used as inputs.

Keywords: Gravity, magnetics, gradients, cross-products, FALCON™

INTRODUCTION

Geophysicists aim to integrate and analyse data and physical properties of a given area, in order to obtain geologically viable interpretations. Different datasets represent different rock properties such as density or magnetic susceptibility. In recent years, new methodologies have emerged based on the idea that different physical properties tend to change at the same location (Zhang and Morgan, 1996; Haber and Oldenburg, 1997; Gallardo and Meju, 2003, 2004; Saunders et al., 2005).

The use of cross-gradient products as a measure of structural similarity in 3-D joint inversions was developed by Gallardo and Meju (2004), and has since been applied to gravity and magnetic data by Fregoso and Gallardo (2009).

In this paper we compute the cross-product of horizontal gradients of airborne vertical gravity and magnetic intensity data. We then use the angle and cross-product values between the horizontal gradients of each dataset to produce a combined product.

We begin with a very brief introduction of the cross-gradient products and review their properties. We test the method on a synthetic model and apply it to FALCON™ airborne gravity gradiometer (AGG) and magnetic data from the western zone of the Halls Creek Orogen, Western Australia.

METHOD

The following theory follows the work of Gallardo and Meju (2003). The 3D cross-gradient function is given by **t** where m_1 and m_2 are any two geophysical model parameters (Equation 1). Following cross-gradient methodology, structural similarity is achieved when **t** equals zero (Equation 2), i.e. when collocated gradient vectors are parallel or one of them is null. For this application, with will use the z-component of the cross-gradient function (t_z) (Equation 3).

$$\mathbf{t}(x, y, z) = \nabla m_1(x, y, z) \times \nabla m_2(x, y, z) \quad (1)$$

$$\mathbf{t}(x, y, z) = 0, \quad (2)$$

$$t_z = \frac{\partial m_1}{\partial x}\frac{\partial m_2}{\partial y} - \frac{\partial m_1}{dy}\frac{\partial m_2}{dx} \quad (3)$$

The z-component quantifies the structural similarities in planes normal to the component direction. Cross-gradient t_z values depend on gradient magnitudes and sine of the angle between the gradient vectors. Theoretically, where t_z is small structural similarity is high. Small t_z values can be generated by small angle values or small gradient magnitudes. For the purpose of this paper, we focus on small angle values between the gradients in areas with different physical properties.

The geophysical model parameters we analyse are commonly used in potential field interpretation: the vertical component of the gravity vector (**g**) and the reduced to magnetic pole total magnetic intensity (TMI_RTP).

The FALCON™ AGG system measures φ_Δ and φ_{xy} gravity gradients (Lee, 2001); from them the vertical gravity gradient (φ_{zz}) and the vertical component of the gravity vector **g** are derived. The resolution of the gravity gradient measurements can be as good as 3.0 Eötvös and 0.15 milligals.

MODELLING

The application of curvatures with existing interpretation methods was tested using a synthetic model (Figures 1, 2 and 3). The model was assigned a density contrast of 0.25 g/cc, a susceptibility contrast of 0.01 SI, a 250m depth to top of model, and 3km body depth extent. The model was also assigned a strike length of 15 km, 10km width, and a 60° dip towards the north-northwest.

As different regions may have different gradient magnitudes, it may be important to normalize the gradients before calculations and experiment with different colour tables and transformations to better visualize the results.

In general, the structural similarity decreases with increasing distance from the structure. Cross-product values are often maximized at corners of the model and minimized over edges, while cross-gradient angles tend to contour the edges of structures. The cross-gradient angle helps to distinguish between directly correlated regions (angles close to 0°), inversely correlated regions (angles close to 180°), and non correlated regions (angles close to 90° or –90°) within the magnetic and gravity data. The cross-gradient angle may also aid in the identification of regions of interest, which can then be viewed with the cross-gradient magnitude image to evaluate structural similarity.

The cross-gradient results of the synthetic model indicate some prospective aspects that can be applied to real geological problems, such as improved edge detection in regions characterized by parallel gravity and magnetic responses or a red colour in the cross-gradient angle imagery.

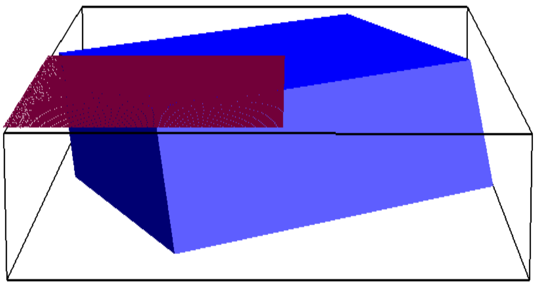

Figure 1. Model 3D view looking south of NNW dipping block with a vertical NE edge.

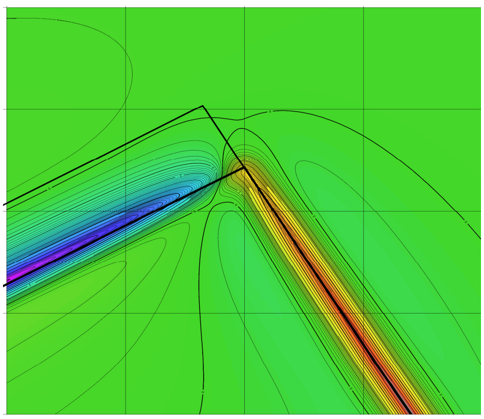

Figure 2. Synthetic model results of the cross-gradient (normalised) magnitude. Magnitudes range from red = 8.78 to purple = –9.02.

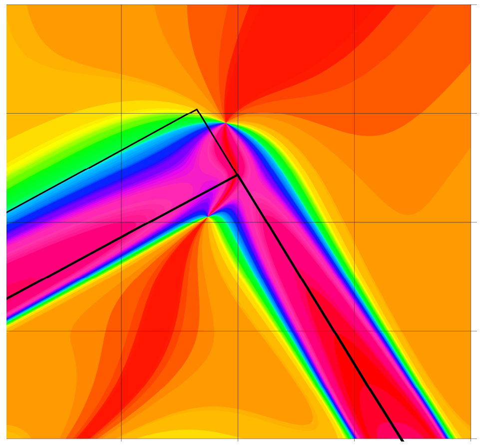

Figure 3. Synthetic model results of cross-gradient angle When the cross gradient angle is 0° or 180° a red colour appears within the data, while angles around 90° appear green.

APPLICATION

The cross-gradient method was applied to FALCON™ AGG data from the western zone of the Halls Creek Orogen, Western Australia (Figure 4). The application of cross-gradient information is presented here with the aim of simply illustrating how our understanding of the cross-gradient relates to the geology.

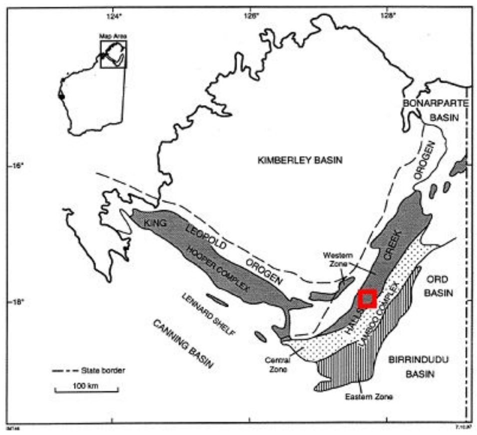

Figure 4. Sketch map outlining the Halls Creek Orogen in Western Australia. The AGG data area presented below is outlined in red (Sheppard et al., 1997).

Figures 5 and 6 display cross-gradient magnitude and angle of the AGG data over a rheologically rigid block within the Western Zone of the Halls Creek Orogen.

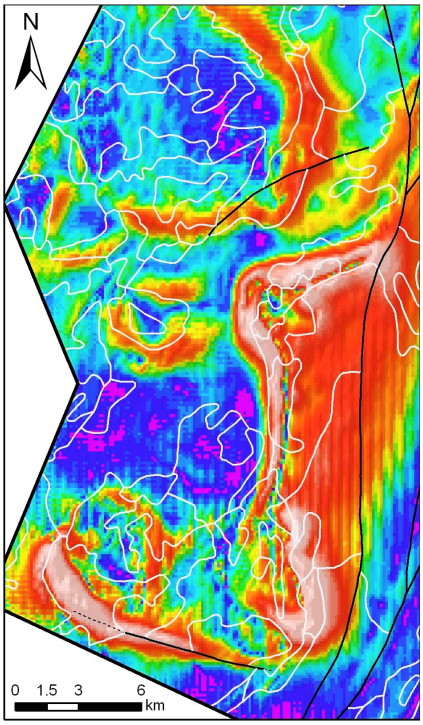

Figure 5. Cross-gradient magnitude imagery overlain by the published 1:1M geology line work in the Halls Creek Orogen, Western Australia (modified from Stewart, A.J. et al., 2008). Faults are shown with black lines, and geological boundaries are shown with grey lines. Values range from 1.0 (red) to 0 (purple).

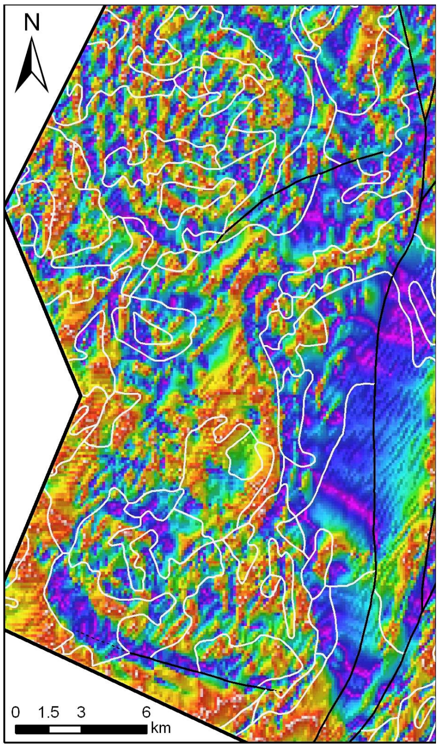

Figure 6. Cross-gradient angle imagery overlain by the published 1:1M geology line work in the Halls Creek Orogen, Western Australia (modified from Stewart, A.J. et al., 2008). Faults are shown with black lines, and geological boundaries are shown with grey lines. Values range from 180° (red) to –180° (purple).

The geology over the area consists primarily of granitoids, dolerite, gabbro, and ultrabasic intrusions, and minor sedimentary units. The published 1:1M scale geology line work (modified from Stewart, A.J. et al., 2008) is overlain on Figures 5 and 6 to display basic similarities and contrasts between the cross-gradient data and previously published work.

Cross-gradients when applied in conjunction with other derivative products including the vertical gravity (gD) and vertical gravity gradient (GDD) have advantages that include improved edge detection and identification of subtle features related to parallel gravity and magnetic responses. Observed highs in the cross-gradient magnitude can often be correlated with high values in the horizontal gradient of the vertical gravity. The cross-gradient angle displays additional subtle features that are often not recognizable in other derivative products of either vertical gravity or TMI_RTP.

CONCLUSIONS

Computing the cross-gradient product of airborne vertical gravity and magnetic intensity data provides a method to aid interpretation by utilising the angle and cross-product values between the horizontal gradients of each dataset.

The cross-gradient method was tested on a synthetic model and applied to FALCON™ airborne gravity gradiometer data from the Halls Creek Orogen, Western Australia. The horizontal gradients of the vertical component of the gravity vector and the reduced to magnetic pole total magnetic intensity were used as inputs.

Cross-gradients values and angles provide another dimension of information to aid geological interpretation, especially the integration of different datasets, and should be included in the standard suite of images used for interpretation.

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