A new source parameters estimation method of airborne gravity gradient tensor data

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SUMMARY

One of the important tasks of potential field interpretation is source parameters estimation of the geological structures, including the horizontal position and buried depth. A new method to interpret airborne gravity tensor data is proposed in this paper based on Normalized Downward Continuation (NDC) of the tensor data directional total horizontal derivatives. The NDC method was introduced for source depth estimation, which can be applied to analytical signal modulus and potential fields themselves. And the maxima of the NDC map mainly correspond to the centre location of the geologic source. We applied the NDC method to the directional total horizontal derivatives which can be used for delineating the sources' horizontal edges. The maximum values of the result indicate the source edges horizontal position and buried depth simultaneously. During the calculation, the iteration method of the downward continuation is used in the NDC calculation process to improve the stability. The new method was tested on synthetic models and obtained satisfactory results. Compared with previous work, this new approach has a better lateral resolution.
Key words: Normalized Downward Continuation (NDC); airborne gravity gradiometry (AGG); directional total horizontal derivatives; source parameters estimation.

INTRODUCTION

In recent years, Airborne Gravity Gradiometry (AGG) has been used as a cost effective tool in both mineral and oil and gas exploration.. There are various publications focused on the processing and interpretation of the Gravity Gradient Tensor data (Mikhailov et al., 2007; Beiki, 2010). Source parameters estimation belongs to the semiautomatic interpretation techniques, which are used to outline the source edges and buried depth (Beiki and Pedersen, 2010; Cooper, 2014; Yuan and Geng, 2014).

Fedi and Florio (2011) applied NDC to analytical signal modulus and potential field, and test the source centre depth estimation performance with different normalized factors. Zhou (2015) applied NDC with mean normalization factor to directional analytic signals (Beiki, 2010) of the gravity gradient tensor data, which can simultaneously get the depth and edge information. But it has poor lateral resolution and inaccurate depth and edge positions when applied to the directional analytic signals in the x and y direction.

Yuan and Geng (2014) defined the directional total horizontal derivatives (DTHD) of the gravity gradient tensor. In this paper, we applied the NDC method to the DTHD of the tensor data to improve the depth and edge estimation precision. The iterative method of downward continuation of gravity gradient tensor data is introduced to compute each downward continuation level field (Xu et al., 2007). A synthetic model is utilized to explain the effectiveness of the new method.

NDC APPLIED TO DTHD

Gravity tensor data are the space derivatives of the components of the gravity field in the three orthogonal directions x, y and z. The tensor matrix can be expressed as:

$$\Gamma=\begin{pmatrix} \frac{\partial^2 U}{\partial x^2} & \frac{\partial^2 U}{\partial x \partial y} & \frac{\partial^2 U}{\partial x \partial z} \\ \frac{\partial^2 U}{\partial y \partial x} & \frac{\partial^2 U}{\partial y^2} & \frac{\partial^2 U}{\partial y \partial z} \\ \frac{\partial^2 U}{\partial z \partial x} & \frac{\partial^2 U}{\partial z \partial y} & \frac{\partial^2 U}{\partial z^2} \end{pmatrix}=\begin{pmatrix} g_{xx} & g_{xy} & g_{xz} \\ g_{yx} & g_{yy} & g_{yz} \\ g_{zx} & g_{zy} & g_{zz} \end{pmatrix}, \tag{1}$$

where U is the gravitational field and U satisfies the Laplace equation in free space based on the theory of the potential field. The tensor matrix is a symmetric matrix and the trace of the matrix is equal to zero. Therefore, the tensor matrix only contains five independent components. Beiki (2010) analysed the analytic signals of the potential field gradient tensor, and defined analytic signals, called directional analytic signals for every row of the potential field gradient tensor matrix. The directional analytic signals (DAS) in x and y direction can be written as:

$$A_x=\sqrt{g_{xx}^2+g_{xy}^2+g_{xz}^2}\,, \tag{2}$$

$$A_y = \sqrt{g_{yx}^2 + g_{yy}^2 + g_{yz}^2}\ , \tag{3}$$

Where, A_x and A_y can outline the N-S and E-W edges. Zhou (2015) applied the NDC method with mean normalization factor to the directional analytic signals A_x and A_y.

Yuan and Geng (2014) proposed the directional total horizontal derivative (DTHD) of potential field, and the definitions are:

$$THD_x = \sqrt{g_{xy}^2 + g_{xz}^2}\ , \tag{4}$$

$$THD_y = \sqrt{g_{yx}^2 + g_{yz}^2}\ , \tag{5}$$

where the subscript x and y denote the direction. The maximum values of THD_x and THD_y can delineate the N-S and E-W edges. We defined edge detector EDT as:

$$EDT = \sqrt{THD_x{}^2 + THD_y{}^2}\ . \tag{6}$$

Fedi and Florio (2011) defined the normalized downward continuation for analytic signal modus and the potential field themselves using different normalizing factors, it can be expressed as:

$$G_N = \frac{G(x, y, z)}{N(z)}\ , \tag{7}$$

where $G(x,y,z)$ is the downward continuation fields at each continuation level z, $N(z)$ is the normalization factor. The maximum values of G_N indicate the sources depth. We applied the NDC method with different normalization factors to EDT for edges and depth position estimation. The expression is:

$$G_N = \frac{EDT}{N(z)}\ , \tag{8}$$

where the mean, geometric mean, harmonic mean and median normalizing factors are chosen for the definition of N(z):

$$N(\mathrm{z}) = \begin{cases} \dfrac{1}{n}\sum_{1}^{n} EDT \\ \sqrt[n]{EDT_1 \bullet EDT_2 \cdots EDT_n} \\ \dfrac{n}{\dfrac{1}{EDT_1} + \dfrac{1}{EDT_2} + \cdots \dfrac{1}{EDT_n}} \\ median[EDT] \end{cases}\ , \tag{9}$$

where n is the totalnumber of measured points.

Marson and Klingele (1993) identified that the total horizontal derivative has better resolution than analytic signal in edge detection. So the NDC method applied to the directional total horizontal derivative has a better lateral resolution than that used to directional analytic signals. In order to compare the different methods results, we used the combination of A_x and A_y for the NDC application, the detector EDA based on A_x and A_y is:

$$EDA = \sqrt{A_x{}^2 + A_y{}^2}\ . \tag{10}$$

APPLICATION TO SYNTHETIC MODEL DATA

We construct a prism model to explain the new method of NDC applied to the EDT based on directional total horizontal derivatives. The buried centre depth of the prism is 25 m and the grid interval is 5 m. The horizontal position of the prism is shown in Fig. 1g. The prism model's gravity gradient components are shown in Fig 1a-f. During the downward continuation EDT and EDA calculations at different levels, the maximum depth is set as 80m and the depth interval is 2m. The downward continuation iteration method proposed by Xu et al. (2007) is applied to calculate the field at each continuation level. We choose the centre profile across the prism to explain the depth estimation results. The NDC method with different normalization factors applied to EDA based on directional analytic signals are shown in Fig 2a-d. The maximum values generally indicate the depth to centre of the source, but it fails to outline the position of the prism edges. Fig3a-d are the source parameter estimation results with NDC method being used to calculate EDT based on the directional horizontal derivatives. The white dots indicate the prism centre depth and horizontal position with satisfactory precision. And different normalization factors can obtain similar depths and edge information with different map displays as Fedi and Florio (2011) indicated. Compared with the performance of NDC applied to EDA (Zhou, 2015), the new method has better lateral resolution with a good correspondence to the source edges and depths. We can plot the source parameters estimation results in a three-dimensional map, which can be used for edge detecting and depth estimation simultaneously, providing better results.. The method also can be used to interpret the real measured AGG tensor data to provide more information about the buried sources.

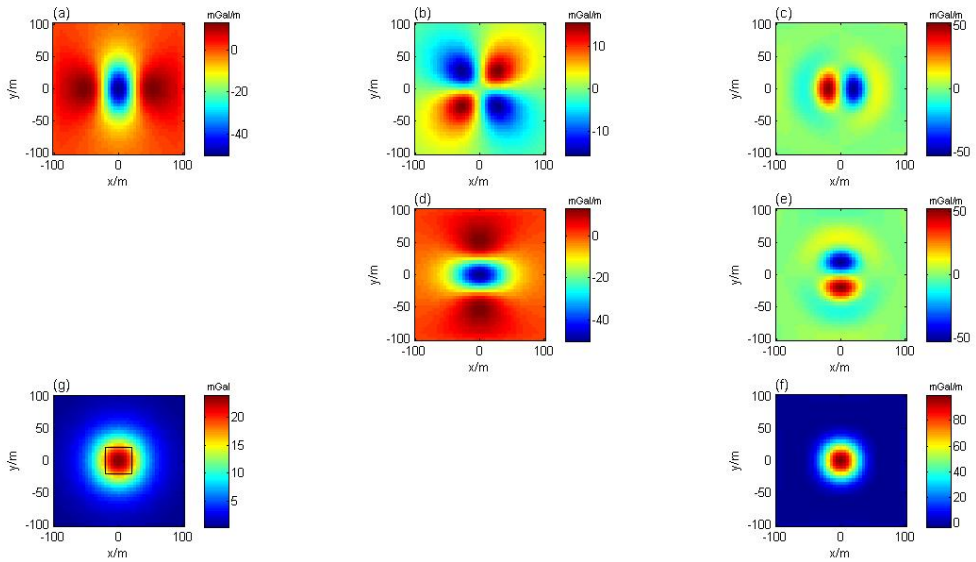

Figure 1: The synthetic gravity gradient tensor data and original gravity anomaly. (a) g_{xx}; (b) g_{xy}; (c) g_{xz}; (d) g_{yy}; (e) g_{yz}; (f) g_{zz}; (g) g_z; The black rectangle in (g) denotes the horizontal position of the prism.

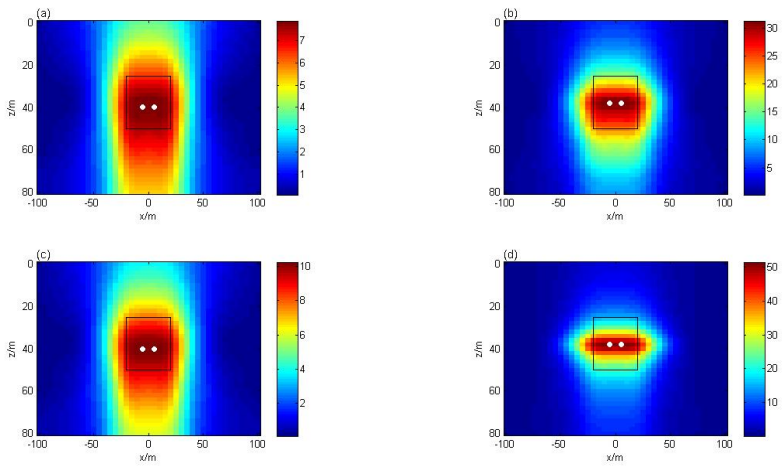

Figure 2: The NDC method with different normalization factors applied to *EDA* based on directional analytic signals. (a) Normalization by mean factor. (b) Normalization by geometric mean factor. (c) Normalization by harmonic mean factor. (d) Normalization by median factor. The white dots denote the maximum values, and the black rectangle denotes the position of the prism in *xoz* profile.

CONCLUSIONS

This paper has applied the NDC with different normalization factors to the edge detector *EDT* deduced from the directional total horizontal derivatives of the gravity tensor data. The maximum values of the results are related to the position of source edges and depth. Compared with previous work applied to the directional analytic signals using the synthetic model, the new technique has better lateral resolution with a better performance in the edge position estimation. The 3D plot of the results is suggested for the real measured AGG tensor data interpretation, which can obtain the edges and depth information with high precision.

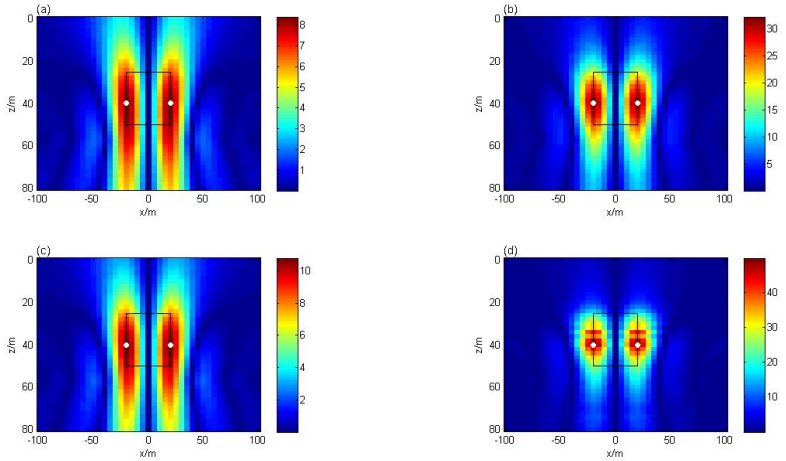

Figure 3: The NDC method with different normalization factors applied to *EDT* based on directional total horizontal derivatives. (a) Normalization by mean factor. (b) Normalization by geometric mean factor. (c) Normalization by harmonic mean factor. (d) Normalization by median factor. The white dots denote the maximum values, and the black rectangle denotes the position of the prism in *xoz* profile.

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