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Source parameters estimation by the normalized downward continuation of gravity gradient data

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ABSTRACT

Normalized downward continuation (NDC) method calculates the normalization on the analytical signal modulus of the downward continued field or the downward continuation of the potential field itself, which is used to obtain the edges position and buried depth information. In this study, we applied the NDC method to the edge detector defined as the combination of the directional total horizontal derivatives (DTHD) to improve the lateral resolution. The iterative downward continuation is introduced in the computation process which has a large downward continuation distance. The synthetic gravity data with and without noise are used to test the effectiveness of the new presented approach. The results show that NDC applied to the edge detector based on DTHD has a better resolution than the previous method based on the directional analytic signals, and the source edges and depth information can be obtained simultaneously. Finally, we apply the method to the gravity data acquired over the Humble Salt Dome in USA. The results show a good correspondence to the previous work results.

1. Introduction

The source parameters estimation of gravity gradient data is an important part for interpretation. The source parameters contain the horizontal position and buried depth. In recent years, there are many semi-automatic interpretation techniques introduced to estimate the source location parameters (Zhang et al., 2000; Beiki, 2010; Cooper, 2014; Ma and Huang, 2015; Sertçelik and Kafadar, 2012). In order to construct the reasonable density model, the constrained gravity inversion requires adequate a priori information regarding the causative physical distribution (Li and Oldenburg, 1998). The source parameters estimation methods can be effective in providing useful source information for inversion. Paoletti et al. (2013) presented self-constrained potential field inversion method based on the a priori information deduced from the potential field itself. Fregoso et al. (2015) generalized the Euler deconvolution method to obtain the source horizontal and vertical positions, and used for joint inversion of magnetic and gravity data. So developing semi-automatic interpretation method with high parameters estimation precision is a vital work.

The normalized full gradient (NFG) method was introduced to locate the source buried depth by the normalization on the analytic signals modulus of the downward continuation potential field (Berezkin, 1973; Zeng et al., 2002; Elysseieva and Pasteka, 2009; Zhang and Meng, 2015). Other people applied the NFG method to electromagnetic data, self-potential data and seismic data (Dondurur, 2005; Sindirgi et al., 2008; Karsli and Bayrak, 2010). Fedi and Florio (2011) applied different normalization factors on analytical signals modulus and the downward continued potential field itself, and the generalized method called normalized downward continuation (NDC). Zhou (2015) applied NDC method with mean normalization factor to directional analytic signals (Beiki, 2010) of the gravity gradient tensor data, which can simultaneously obtain the depth and edge information. But it has poor lateral resolution and obtains inaccurate depth and edges position when applied to the directional analytic signals in x and y directions in complex geological cases.

Yuan and Geng (2014) defined the directional total horizontal derivatives (DTHD) of gravity gradient data with better resolution than directional analytical signals (DAS). In this paper, we calculate the normalization on DTHD of the downward continued field to improve the depth and edges estimation precision. The iterative downward continuation method of gravity gradient data is introduced to compute each downward continuation level field (Xu et al., 2007). The synthetic models with and without noise and the measured gravity field are utilized to explain the new method effectiveness.

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2. NDC of directional total horizontal derivatives

2.1. Directional total horizontal derivatives

Gravity tensor data are the space derivatives 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 potential and U satisfies the Laplace equation $\nabla^2 U = 0$ 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) analyzed the analytic signals of the potential field gradient tensor, and defined directional analytic signals for every row of the potential field gradient tensor matrix. The directional analytic signals (DAS) in x and y directions 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. The edge detector based on the A_x and A_y is (Beiki, 2010):

$$EDA = \sqrt{{A_x}^2 + {A_y}^2}. \tag{4}$$

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

$$THD_x = \sqrt{g_{xy}^2 + g_{xz}^2}, \tag{5}$$

$$THD_y = \sqrt{g_{yx}^2 + g_{yz}^2}, \tag{6}$$

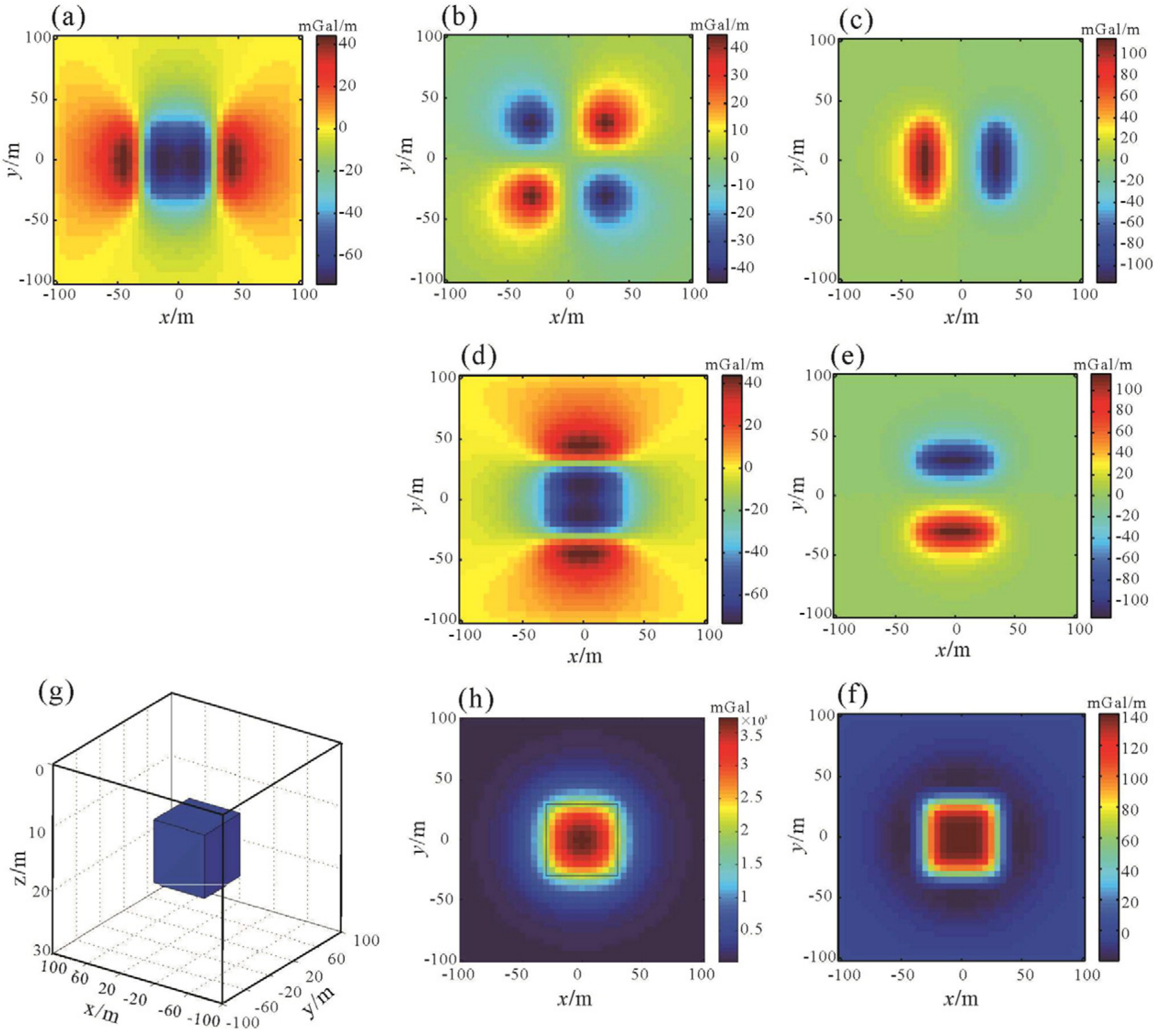

Fig. 1. The constructed prism and the related gravity gradient tensor data. (a) g_{xx}; (b) g_{xy}; (c) g_{xz}; (d) g_{yy}; (e) g_{yz}; (f) g_{zz}; (g) 3D view of the prism; (h) g_z.