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A new method of edge detection based on the total horizontal derivative and the modulus of full tensor gravity gradient

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ABSTRACT

With the rapid development of gravity gradient measurement, the full tensor gravity gradient data has been used more and more frequently in the edge detection. This article focuses on the problem that the effect of edge detection of deep geological body is not clear and false edges among positive and negative anomalies using the common edge detection method. We present a new edge detection method which is based on the total horizontal derivative and the modulus of full tensor gravity gradient. Comparing with the model experiments, it is proved that this method is clearer and more accurate in detecting the edges of geological body especially for the deep model with almost no false edge interference. Finally, the method is applied to the processing of the actual data in St. Georges Bay, Canada, and the edge results are satisfying.

1. Introduction

Along with the rapid development of the high precision air and marine gravity gradient measurement instrument, the gravity gradient measurement has been developed to the stage of commercial application. Gravity gradient tensor data, which can provide more accurate and detailed information of the geological body, contains higher frequency information than traditional gravity data. Concerning the edge detection technology of potential field data, gravity gradient data has got more utilization (Wang et al., 2015; Zhou et al., 2013; Yuan et al., 2014). The accurate extraction of edge information can provide more information about the prior parameters of the target geological body as a basis for further interpretation work.

The vertical derivative (Evjen, 1936) is the first method for edge detection of geological body. After that, the total horizontal derivative (Verduzco et al., 2004; Ma and Li, 2012) is proved to be a more effective means whose maximum value corresponds to the edge's location. Hsu et al. (1996) used higher order analytic signal to identify the edges, which improved the resolution of the inversion edge. Miller and Singh (1994) proposed the first equilibrium edge detection tool–Tilt angle method, which can balance the amplitude between different intensity anomalies well. The improved tilt angle method, from Cooper and Cowan (2006), was used for detecting edges of anomalous body. Wijns et al. (2005) proposed the Theta map method to detect edges.

With the analysis to the inversion results of the above edge detection methods, there have been two main existing defects. One is that the recognition result of the edges of the deep geological body is blurred; the other one is that the false boundaries appear between the positive and negative anomalies, thus interfere the effect of edge detection. Yuan et al. (2016) proposed that the ED method based on the gravity gradient tensor can weaken the above defects. However, the result of ED method will be affected by the trend of the geological body in the model test. On this basis, this paper presents a new edge detection method which is based on the total horizontal derivative and the modulus of gravity gradient tensors, and the result shows that the proposed method is well effective by the comparison of the model tests. Finally, it applies the method to the real full gravity gradient tensor data in St. Georges Bay, Canada, and the result is more accurate than the other methods.

2. Theory

The gravity gradient tensors, which are the second derivatives of gravitational potential G (Minkus and Hinojosa, 2001) in Cartesian coordinate system, can be written as:

$$T = \begin{bmatrix} \frac{\partial G_x}{\partial x} & \frac{\partial G_x}{\partial y} & \frac{\partial G_x}{\partial z} \\ \frac{\partial G_y}{\partial x} & \frac{\partial G_y}{\partial y} & \frac{\partial G_y}{\partial z} \\ \frac{\partial G_z}{\partial x} & \frac{\partial G_z}{\partial y} & \frac{\partial G_z}{\partial z} \end{bmatrix} = \begin{bmatrix} G_{xx} & G_{xy} & G_{xz} \\ G_{yx} & G_{yy} & G_{yz} \\ G_{zx} & G_{zy} & G_{zz} \end{bmatrix}. \quad (1)$$

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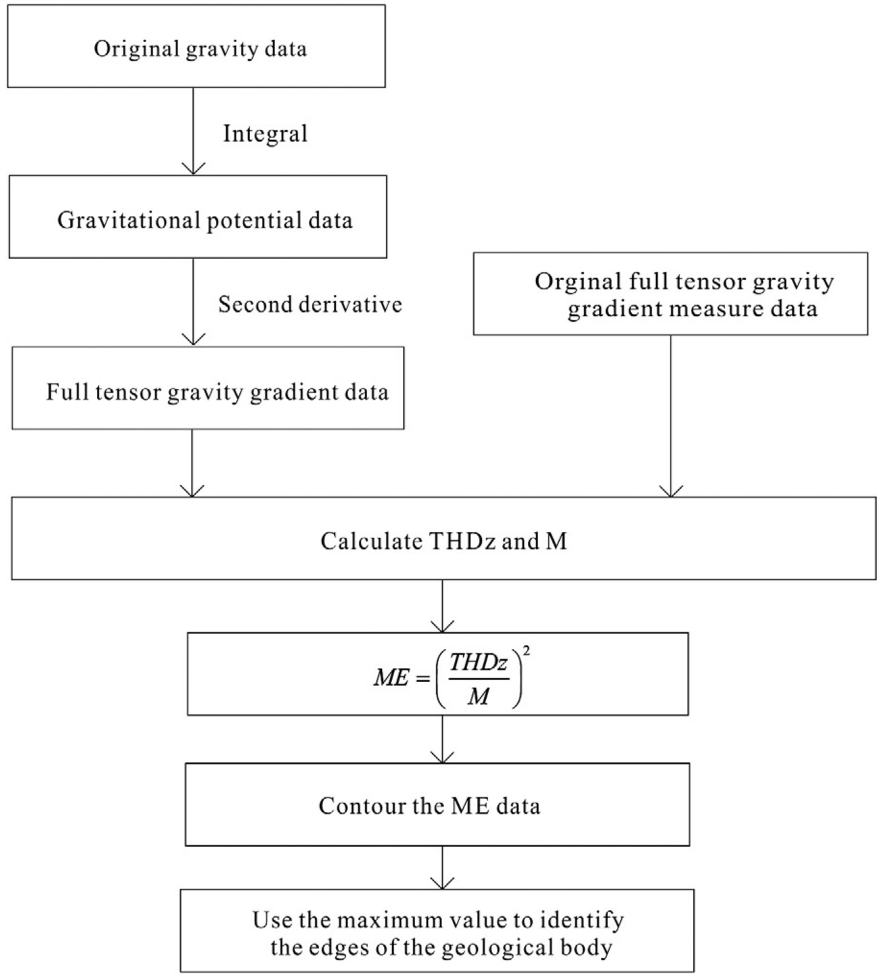

Fig. 1. Flow chart of ME method.

It is a symmetric matrix, so that Gxy = Gyx, Gxz = Gzx, and Gyz = Gzy. By the potential field theory, the gravitational potential satisfies the Laplace equation in the outside of the geological body (Beiki, 2010).

$$G_{xx} + G_{yy} + G_{zz} = 0 \tag{2}$$

So, the trace of the matrix is equal to 0. It consists of only 5 independent tensors Gxx, Gxy, Gxz, Gyz, and Gzz.

The modulus of gravity gradient tensors is expressed as:

$$M = \sqrt{(Gxx)^2 + (Gxy)^2 + (Gxz)^2 + (Gyy)^2 + (Gyx)^2 + (Gyz)^2 + (Gzz)^2 + (Gzx)^2 + (Gzy)^2}. \tag{3}$$

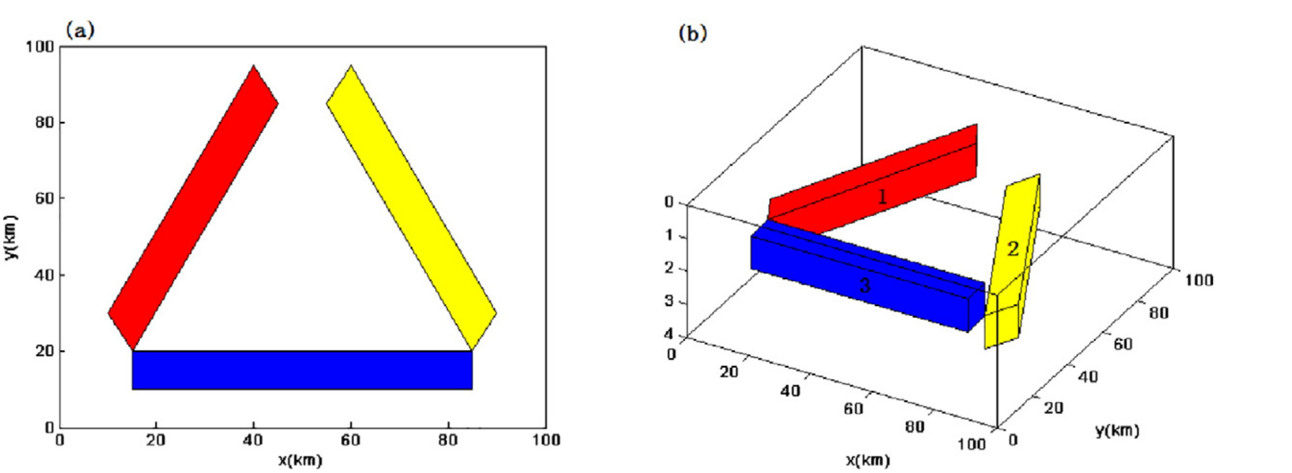

Fig. 2. Plan view and 3D view of the synthetic model.

Yuan and Geng (2014) and Yuan and Yu (2015) have defined the directional total horizontal derivatives, THDx, THDy and THDz, to interpret the gravity gradient tensor data, the expressions are:

$$\begin{cases} THDx = \sqrt{(Gxy)^2 + (Gxz)^2} \\ THDy = \sqrt{(Gyx)^2 + (Gyz)^2} \\ THDz = \sqrt{(Gzx)^2 + (Gzy)^2} \end{cases} \tag{4}$$

Based on the above two equations, a new method of edge detection (ME) based on horizontal derivative and the modulus of gravity gradient tensors is defined:

$$ME = \left(\frac{THDz}{M}\right)^2. \tag{5}$$

This method uses the maximum value to identify the edges of the geological body. And there is a flow chart of ME method (Fig. 1.).

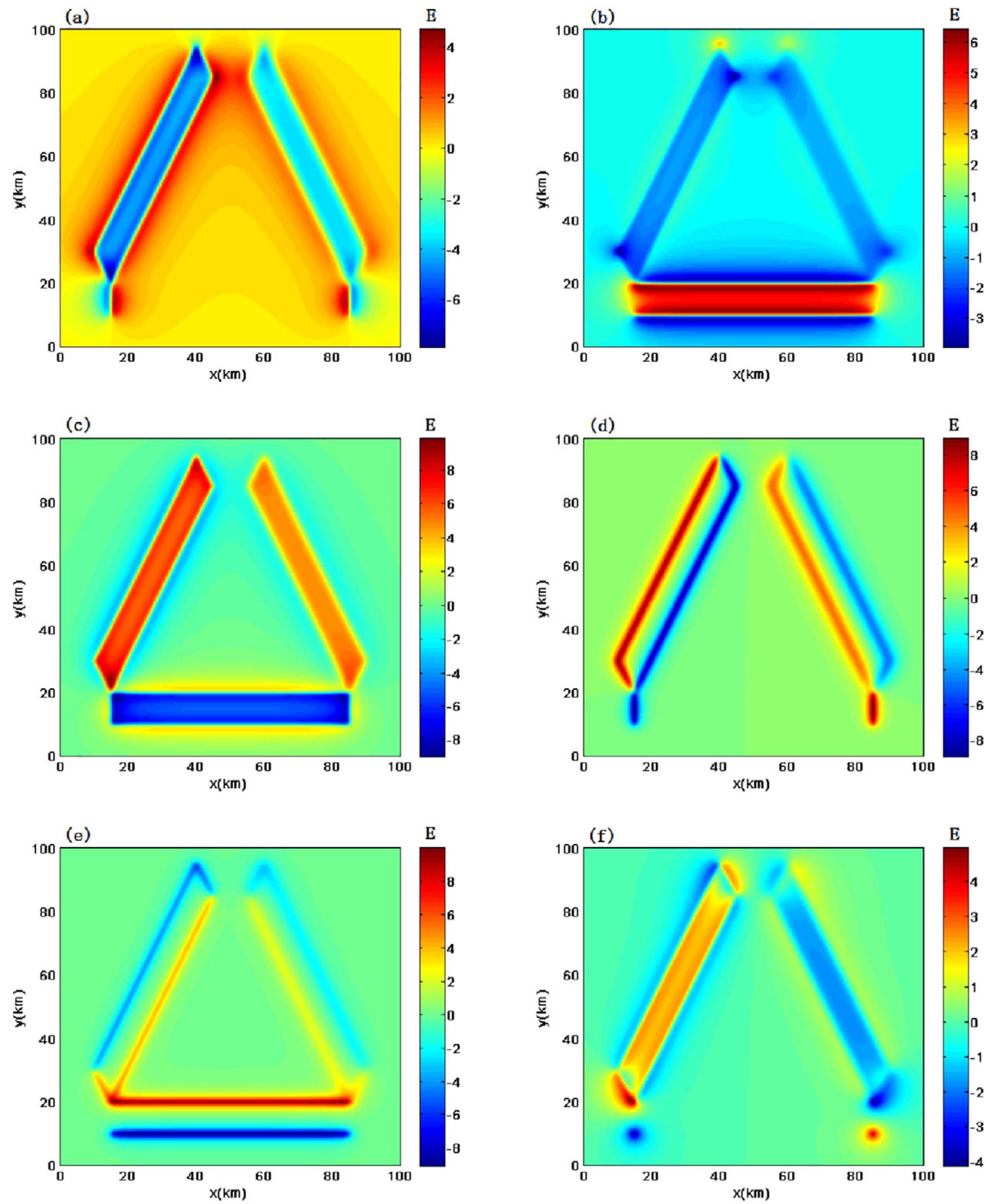

Fig. 3. Synthetic gravity gradient tensor data of model 1. (a) Gxx; (b) Gyy; (c) Gzz; (d) Gxz; (e) Gyz; (f) Gxy.

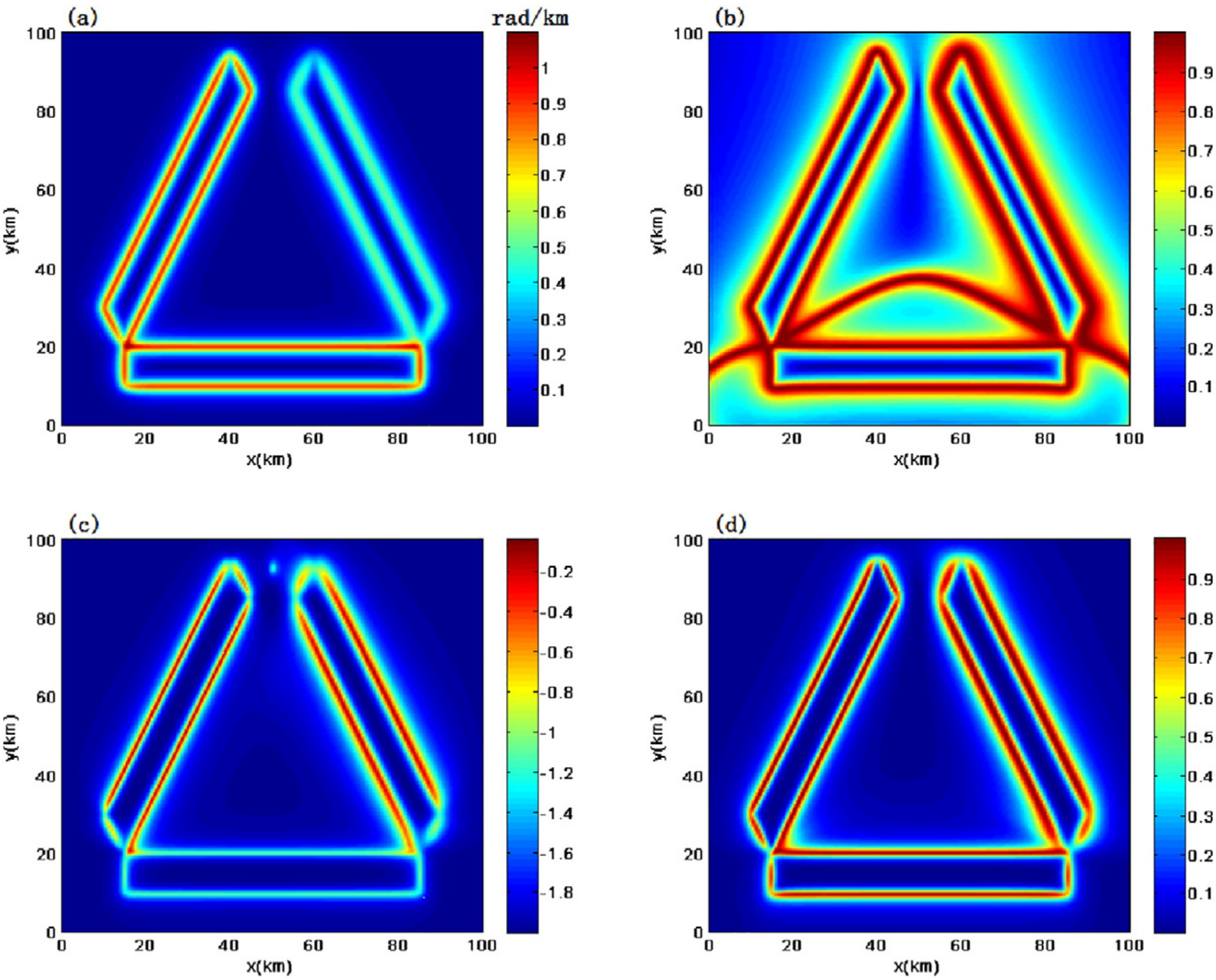

Fig. 4. Edge results of gravity gradient tensor data (a) edge of THDR; (b) edge of Theta map; (c) edge of ED; (d) edge of ME.

Original full tensor gravity gradient measure data can be directly used to calculate the ME data.

Original gravity data g (g = Gz) need to be transformed to full tensor gravity gradient for further calculation. The integral original gravity data in frequency domain can get gravitational potential data G. Gxx, Gyy and Gxy are the second derivative of gravitational potential data G. Gxz, Gyz and Gzz are the first derivative of gravity data Gz. We can directly calculate all of them in frequency domain. Calculating in frequency domain is faster and easier than in space domain. Therefore we use the numerical scheme in frequency domain to get full tensor gravity gradient data in this paper.

3. Model experiments

In order to verify the effectiveness of the method in edge detection, we compare the proposed method with three other generally applied

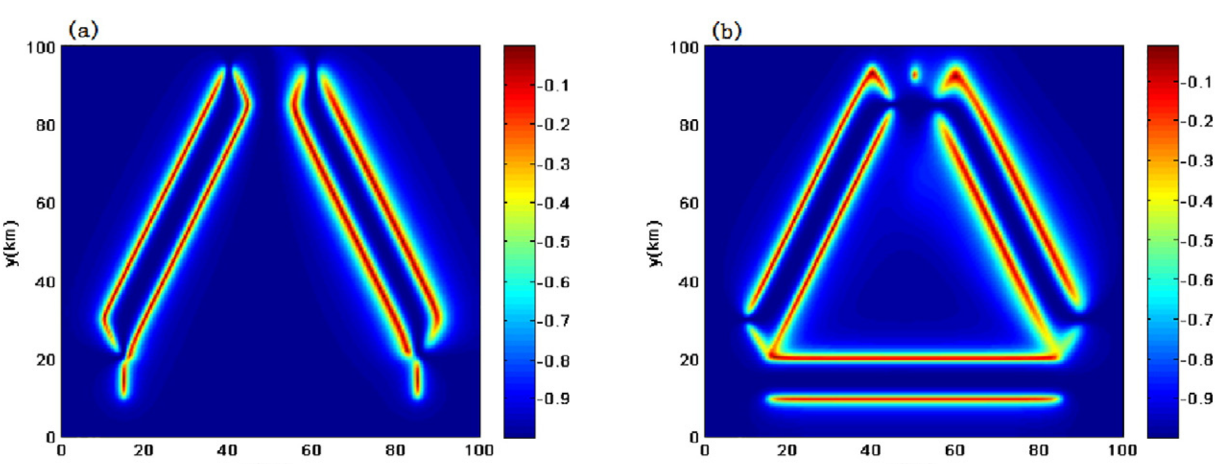

Fig. 5. Components of ED (a) ThetaX; (b) ThetaY.

methods: the total horizontal derivative method (THDR), Theta map method and ED method (Yuan et al., 2016).

Considering that the result of edge detection may be affected by the strike of geological body, it designs two models which have a certain angle with the X axis, as shown in Fig. 2a. Fig. 2b shows a 3-D view of the models. Range of observation is 10 km × 10 km, with a spacing of 0.2 km. Model 1's top and bottom are 1 km and 2 km, respectively, and residual density is 0.1 g/cm^3. Model 2's top and bottom are 2 km and 3 km, respectively, and residual density is 0.1 g/cm^3. Model 3's top and bottom are 1 km and 2 km, respectively, and residual density

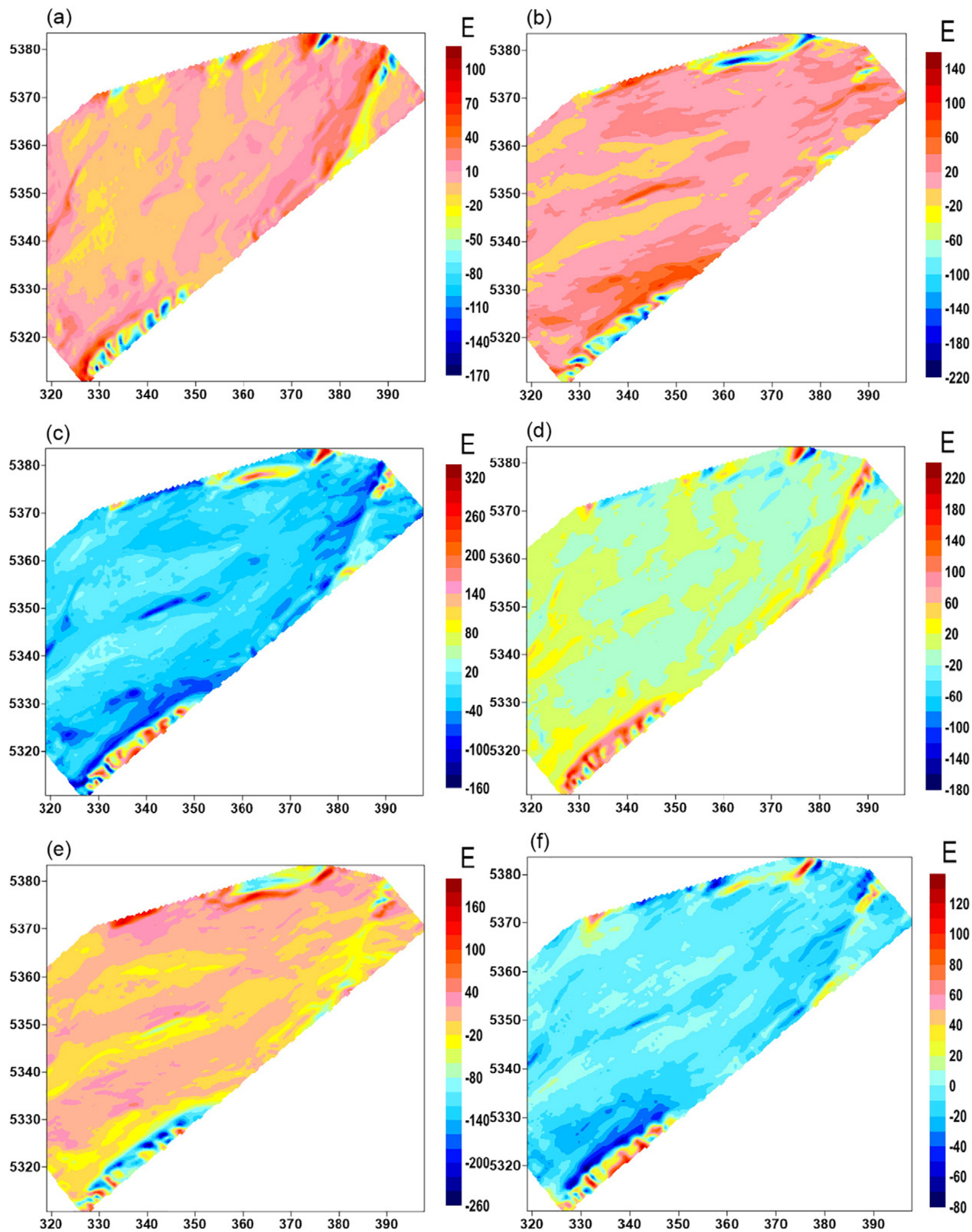

Fig. 6. Full tensor gravity gradient data in St. George's Bay. (a) Gxx; (b) Gyy; (c) Gzz; (d) Gxz; (e) Gyz; (f) Gxy.

is −0.1 g/cm^3. Design of model considers the influence of the different depth and the positive and negative anomalies of geological body on edge detection.

Fig. 3 shows gravity gradient tensors Gyy, Gxx, Gzz, Gxz, Gyz, and Gxy of the model. Fig. 4 shows THDR, Theta map, ED, and ME method of edge detection effect. The THDR method has different effects in detecting the boundaries of geological body of different depths with the detected edges in which model 2 is not as clear as models 1 and 3 (Fig. 4a). The Theta map method (Fig. 4b) is positive over the model, but shows false edges in the middle of the graphic which is caused by the positive and negative anomalies. It can be concluded that Theta map method is affected by the gradient between the positive and negative anomalies, but not the depth.

The ED method (Fig. 4c) can detect all the edges, but the result of model 3 is not clear as models 1 and 2. It is assumed that the effect is caused by the trend of the model body. The ME method (Fig. 4d) can locate all the edges of models clearly without any false edges. It is satisfactory that ME method is almost not affected by the depth and gradient zone between positive and negative anomalies. Quantitative analysis of the results of ED method and ME method are shown as follows. In the result of ED method, the maximum value at the boundary of models 1 and 2 is about −0.1, and of model 3 is about −1, which is one order of magnitude difference. In complex structures, the smaller boundaries may be covered by larger boundaries, and are not easily distinguishable. In the ME method, the maximum value of the boundary of models 1, 2 and 3 is about 1, and the difference is small, which is more favorable for boundary recognition.

The analyses to the influence of the ED method as follows:

$$ThetaX = -\frac{\sqrt{Gxx^2 + Gyx^2}}{\sqrt{Gxx^2 + Gxy^2 + Gxz^2}} \tag{6}$$

$$ThetaY = -\frac{\sqrt{Gyx^2 + Gyy^2}}{\sqrt{Gyx^2 + Gyy^2 + Gyz^2}} \tag{7}$$

$$ED = ThetaX + ThetaY. \tag{8}$$

Fig. 5 represents the components of ED method. It's easy to find that the results of ThetaX (Fig. 4a) and ThetaY (Fig. 4b) have the same maximum and easy to identify the boundary of the geological body of model 1 and model 2. However, in model 3, the method of ThetaX can only identify the edge which is orthogonal to the X-axis and ThetaY can only identify the edge which is orthogonal to the Y-axis. The method of ED is composed of ThetaX and ThetaY and the maximum is the way to identify the edge, so we could find that the edge maximum value of model 1 and model 2 is twice that of model 3, and the edge of model 3 is blurred which is not useful for the edge extraction in the actual application.

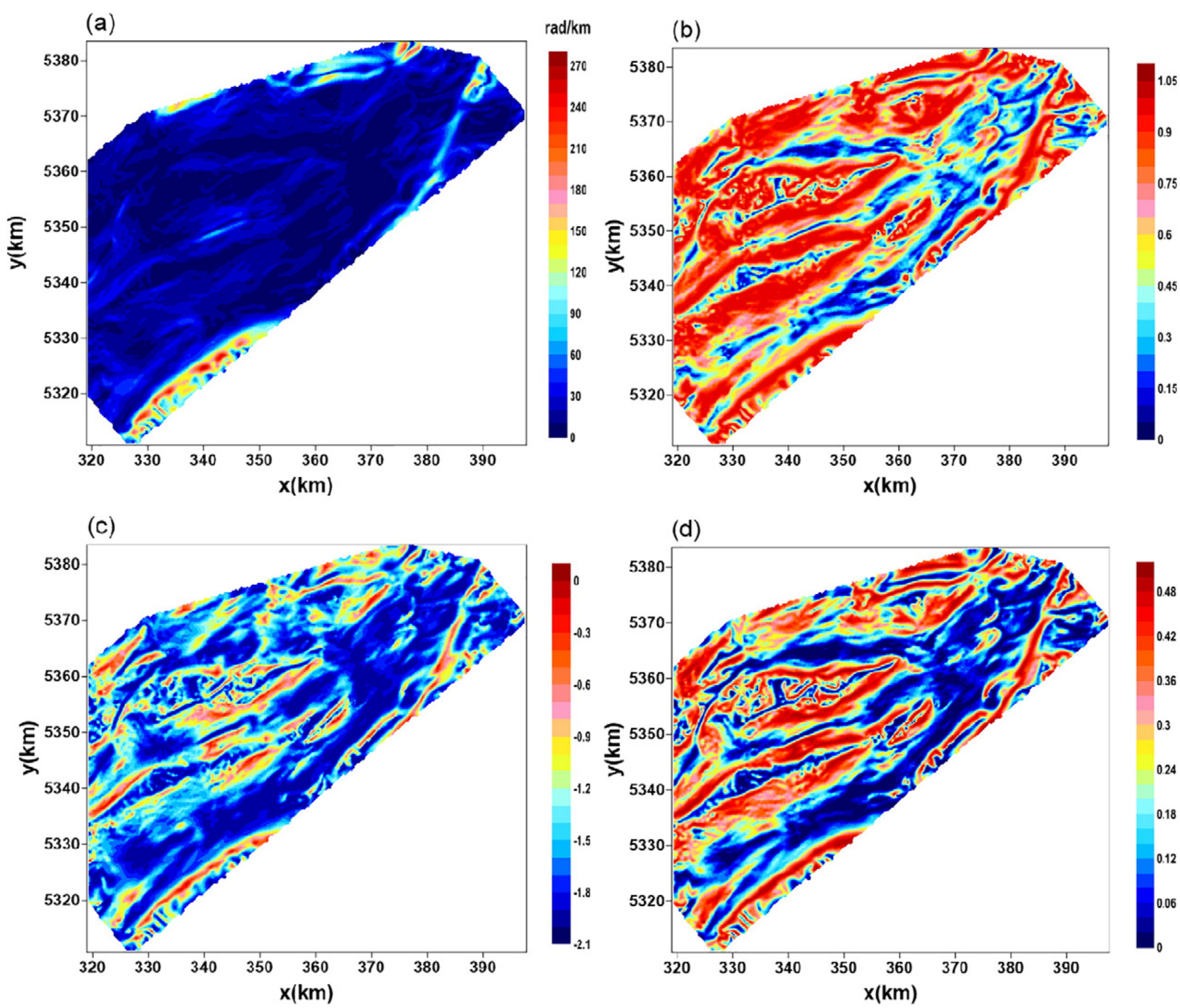

Fig. 7. Edge results of St. George's Bay. (a) edge of THDR; (b) edge of Theta map; (c) edge of ED; (d) edge of ME.

4. Applied to real data

The actual data is the St. George's Bay's full tensor gravity gradient measurement data that is provided by the Natural Resources Canada., including 88 measuring line of which spacing is 400 m. It contains 6602 linear kilometers and encompasses an area of about 3056 km^2. The survey was designed as a constant 80 m altitude. Nineteen tie lines were acquired 5000 m apart. The lines are flown North-East to South-West with perpendicular tie lines. The St. George's Bay full tensor gravity gradient data is shown in Fig. 6.

The edge results of THDR, Theta map, ED and ME over the actual data are shown in Fig. 7. We can see that THDR (Fig. 7a) is influenced by depth, and only a few edges are identified. Theta (Fig. 7b) is affected by the positive and negative anomaly gradients. The recognition result contains false edges, and the range of edges is too large. Fig. 7c and d represents the comparison of the methods of ED and ME. We could recognize that the result of ME is clearer, the continuity of the large structures is much better, the details are clearer, so the method of ME is much better for geological interpretation.

5. Conclusions

The main work is proposing a new edge detection method (ME) based on the total horizontal derivative and the modulus of gravity gradient tensors. Through the model experiments, it is proved that ME makes up the shortcoming of conventional edge detection methods, which detection result for deep geologic body is not obvious and contains false edges between positive and negative anomalies. Compared with the ED method, the advantage of ME is that it is not affected by the strike of geological body. Furthermore, we analyze the reason of ED method that is affected by the strike of geological body. Finally, the method is applied to the actual data processing. Through the comparison with other methods, the ME method gets the more satisfactory edge detection results.

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