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A stable iterative downward continuation of potential field data

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ABSTRACT

Downward continuation is a useful tool in the processing of potential field data, which can effectively enhance weak anomalies and identify overlap anomalies, but we all know that the computation of downward continuation is unstable, and easily distorts the true feature of potential field data. Because the computation of upward continuation and horizontal derivatives is stable, we proposed using the combination of upward continuation and horizontal derivative to accomplish the downward continuation of potential field data. The proposed method is demonstrated on synthetic potential field data, and the results show that the proposed method can finish the downward continuation of the data stably and precisely, and the precision of the proposed method is higher than the traditional method. We also apply it to real potential field data, and the results show that the proposed method accomplishes the downward continuation of the real data stably.

Introduction

Continuing potential field (gravity and magnetic) at one plane from the sources to another plane either closer or farther which has been applied in numerous applications, can enhance the signal of shallow sources effectively. Essentially the signal of the sources in the frequency domain is observed at an observing plane, and is multiplied by a continuation factor of either upward or downward to continue the data. Upward continuation is a stable computation, at higher heights, which is the contribution of the most extended sources. Downward continuation can dramatically enlarge the smallest changes in the original potential field data, but the computation of the downward continuation is unstable and sensitive to noise. Thus, downward continued data must be filtered strictly. Baranov (1975) derived the downward continuation formula based on the potential field theory, but this method is strongly dependent on the sampling interval of the original data and is able to downward continue only to very shallow depths — equal to a multiple of only several sampling spaces from 2 to 10 (Xu et al., 2007). Many methods have been presented on how to process this kind of instability occurring during downward continuation of potential field data (Abedi et al., 2013; Berezkin and Buketov, 1965; Cooper, 2004; Fedi and Florio, 2002, 2011; Pasteka et al., 2012; Pawlowski, 1995; Trompat et al., 2003).

In this paper, we use the combination of the upward continuation and horizontal derivative to accomplish the downward continuation of potential field data, which can effectively improve the precision and stability of the results.

2. Methodology

Downward continuation calculates the potential field data that is closer to the causative sources. Potential field data at two observation heights are related by the continuation relation (Blakely, 1995; Fedi and Florio, 2002; Li and Devriese, 2009), which can be given by

$$T(x,y,h)=\frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\frac{T(x',y',0)h}{\left[(x-x')^2+(y-y')^2+h^2\right]}dx'dy' \tag{1}$$

where, $T(x',y',0)$ and $T(x,y,h)$ represent respectively the potential field data at two observation heights separated by a vertical distance h, $h>0$ represents upward continuation, and $h<0$ represents downward continuation.

Applying a two-dimensional Fourier transform to the Eq. (1) we can get

$$T(x,y,h)=F^{-1}\left[e^{-\sqrt{k_x{}^2+k_y{}^2}h}\widetilde{T}\left(k_x,k_y\right)\right] \tag{2}$$

where, $\widetilde{T}\left(k_x,k_y\right)$ is the Fourier transform of $T(x',y',0)$, (k_x,k_y) are the wavenumbers in x and y directions, and $e^{-\sqrt{k_x{}^2+k_y{}^2}h}$ is known as the continuation factor.

The operation of downward continuation is mathematically effective in the source free area above the ground (Blakely, 1995), and it is numerically unstable and sensitive to noise. Some people (Even, 1936; Fedi and Florio, 2002) present using the Taylor series to finish this work, which can be expressed as

$$T(x,y,h)=T(x,y,0)+\frac{\partial T}{\partial z}h+\frac{1}{2!}\frac{\partial^2 T}{\partial z^2}h^2+\cdots+\frac{1}{m!}\frac{\partial^m T}{\partial z^m}h^m \tag{3}$$

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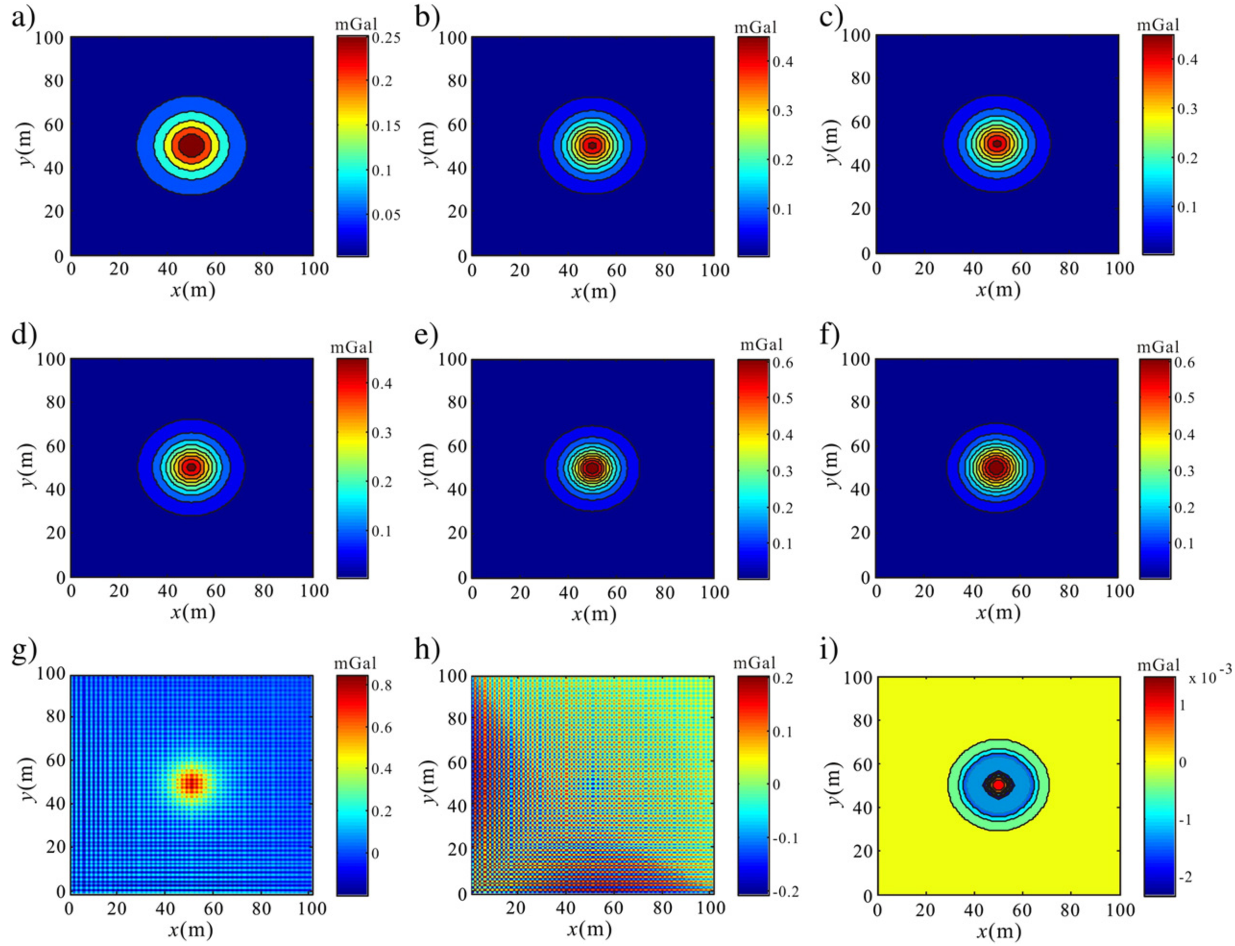

Fig. 1. (a) Gravity anomaly generated by a sphere with a depth of 15 m; (b) gravity anomaly generated by a sphere with a depth of 12 m; (c) downward continuation of the data in (a) by 3 m computed by the proposed method; (d) downward continuation of the data in (a) by 3 m computed by Eq. (2); (e) synthetic gravity anomaly generated by a sphere with depth of 10 m; (f) downward continuation of the data in (a) by 5 m computed by the proposed method; (g) downward continuation of the data in (a) by 5 m computed by Eq. (2); (h) Difference between the data in (e) and (g); (i) difference between the data in (e) and (f).

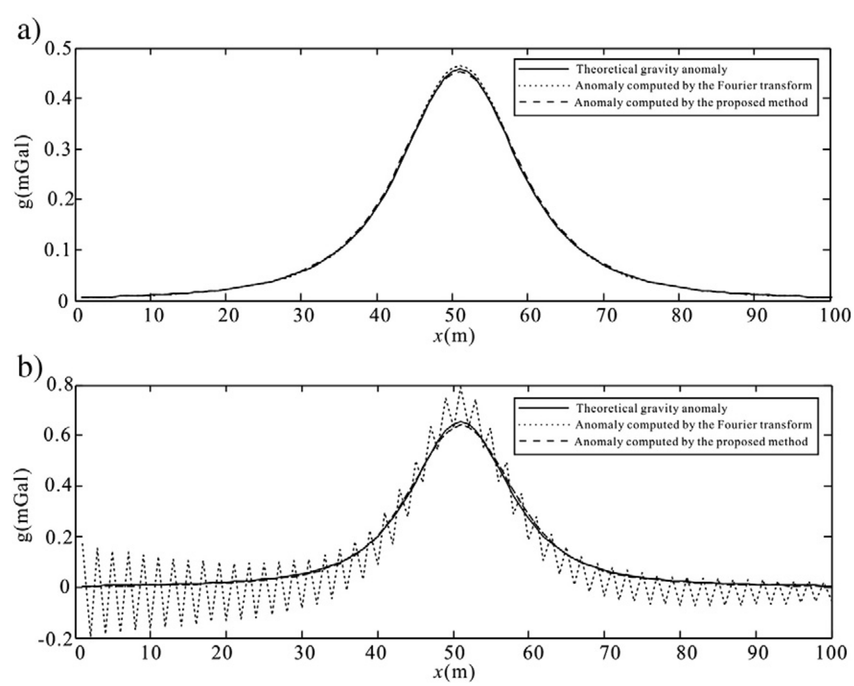

Fig. 2. (a) The anomalies at the level of −3 m computed by different methods; (b) the anomalies at the level of −5 m computed by different methods.