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The antisymmetric factor method for magnetic reduction to the pole at low latitudes

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ABSTRACT

We analyze the characteristics of the wavenumber-domain factor for magnetic reduction to the pole (RTP) at low latitudes, and then propose a new wavenumber-domain method for RTP at low latitudes, herein called the antisymmetric factor method, based on modification of the RTP factor. The method applies the antisymmetric factor in a given scope of directions centered along the magnetic declination to suppress amplification of the RTP factor, stabilizing the RTP. Meanwhile it utilizes the routine RTP factor in other directions to preserve the effective RTP features. The test on the synthetic data demonstrates that the method is robust and effective. Finally, we use the new method, as well as a variable magnetic inclinations algorithm, to perform RTP on the real data of total magnetic intensity anomalies in the South China Sea, and obtain the reliable RTP anomalies.

1. Introduction

The reduction-to-the-pole (RTP) of magnetic anomalies is an important task in the interpretation that transforms total magnetic intensity (TMI) anomalies in oblique magnetization into that as in a vertical magnetization. Thus, the complexity of the TMI anomalies caused by oblique magnetization can be eliminated. However, the RTP factor is one of the amplifying transformation factors. It is related directly to the magnetic inclination. At low latitudes (an absolute inclination less than 20°), the smaller the absolute value of the magnetic inclination is, the stronger the amplification effect of the RTP factor will be. Such amplification upon the noise in the TMI anomalies (which always exists in the real world) causes linear artifacts along the direction of magnetic declination. Therefore, the RTP procedure at low latitudes is much more troublesome than at high latitudes (an absolute inclination larger than 20°).

To overcome the difficulty of RTP at low latitudes, several special RTP methods or techniques were proposed, such as the equivalent source inversion method (Silva, 1986), the Werner filtering (Hansen and Pawlowski, 1989), the energy balance technique (Keating and Zerbo, 1996), the inversion-based method (Li and Oldenburg, 2001), the pseudo inclination method (Macleod et al., 1993), the azimuthal filtering (Phillips, 1997) and the suppressing factor method (Yao et al., 2003).

The equivalent source inversion method solves the RTP instability by inversing the magnetic data to derive equivalent sources and then doing forward modeling to produce the RTP data. However, the inversion requires expensive computation, making the method unsuitable for large-scale magnetic data. The Wiener filtering method utilizes a regularized RTP operator based on Wiener filter (Clarke, 1969; Wiener, 1949), which is a denoising filter. But the method tend to overly smooth the RTP result and to lose signal at short wavelengths (Li, 2008). The energy balance technique suppresses noise effects by iterative blanking so that the average energy is similar in all directions while retaining some signal at short wavelengths. However, the technique is subjective in choosing the related noise assumption and control parameters. The inverse-based method constructs the RTP anomalies model by inversing the observed magnetic data in the wavenumber domain with explicit regularization and an imposition of power spectral decay. But the application of the method is limited due to the complicated inversion and its expensive computation.

All of the pseudo inclination method, the azimuthal filtering and the suppressing filter method are based on modifying the RTP factor in the wavenumber domain to suppress the amplification effect along and near the direction of magnetic declination. The pseudo inclination method replaces the actual magnetic inclination with a larger pseudo inclination in the RTP calculations. The azimuthal filtering tapers the RTP factor by a special sine function, while the suppressing filter method applies a special cosine function. However, all the three methods apt to lose parts of the effective RTP anomalies, respectively because the pseudo inclination method also suppresses the amplification effect in other directions outside the declination, the suppressing filter method overly suppress the amplification effect along the declination (Shi et al., 2012) and the azimuthal filtering has the similar limitation.

In this paper, we first analyze the characteristics of the RTP factors of the routine RTP method and the pseudo inclination method, as well as their drawbacks in applications in RTP at low latitudes. Then we optimize the RTP factor and propose an antisymmetric factor method

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for RTP at low latitudes. The method applies the antisymmetric factor in a certain scope of directions centered along the magnetic declination, while it utilizes the routine RTP factor in other directions. Finally, we test the method both on the synthetic magnetic data and on the real TMI anomalies data in the South China Sea. The routine RTP method and the pseudo inclination method are also used to test the data for comparisons.

2. Method

2.1. The RTP methods based on modifying the RTP factor

In magnetic exploration, we usually observe the TMI anomaly. The corresponding observation direction coincides with the geomagnetic field. Suppose that the remanent magnetization can be neglected and the magnetization direction is consistent with the geomagnetic field. Then the RTP factor in a wavenumber domain can be written in a polar coordinate system as (Gunn, 1975; Macleod et al., 1993; Spector and Grant, 1970)

$$H(r,\theta) = H(\theta) = \frac{1}{[\sin(I) + i\cos(I)\cos(D-\theta)]^2}, \tag{1}$$

where, $r = \sqrt{u^2+v^2}$, $\theta = tg^{-1}(v/u)$, u and v are respectively the wavenumbers in x and y directions, I and D are respectively the inclination and declination of magnetization, and $i = \sqrt{-1}$.

The RTP factor $H(\theta)$ in Eq. (1) is one of the amplifying transformation factors, which is a mono-function of angle θ, while directly related to magnetic inclination I and declination D. At low latitudes, the absolute value of I is relatively small. When θ approaches $D \pm 90°$, the amplitude of $H(\theta)$ grows rapidly to large values. In extreme conditions, $I = 0$ and $\theta = D \pm 90°$, there is $H(\theta) \to -\infty$. Such amplification effect of $H(\theta)$ at low latitudes makes calculation of RTP very unstable, yielding notable stripes (linear artifacts) along the magnetic declination D in the RTP results. Therefore, it is necessary to modify the RTP factor to suppress the amplification effect along the magnetic declination, so that calculation will be stable and the stripes will be reduced or even vanish. Three such methods include the pseudo inclination method (Macleod et al., 1993), the azimuthal filtering (Phillips, 1997) and the suppressing factor method (Yao et al., 2003). Here, we select the pseudo inclination method as an example to analyze the characteristics of the RTP factor.

The RTP factor of the pseudo inclination (PI) method in a polar coordinate system is written as (Macleod et al., 1993)

$$H_{PI}(\theta) = \frac{[\sin(I) - i\cos(I)\cos(D-\theta)]^2}{[\sin^2(I') + \cos^2(I')\cos^2(D-\theta)] \cdot [\sin^2(I) + \cos^2(I)\cos^2(D-\theta)]}, \tag{2}$$

where I' is the pseudo inclination defined by the user, which is larger than the real one I. If $|I'| < |I|$, there is $I' = I$. In practice, the absolute value of I' is often set between 20° and 30° (Macleod et al., 1993), and it needs to be larger for stronger noise in the observed anomalies data (Li, 2008).

In the extreme case of the magnetic equator, where $I = 0°$, the substitution into Eq. (2) yields

$$H_{PI}(\theta) = \frac{-1}{[\sin^2(I') + \cos^2(I')\cos^2(D-\theta)]}. \tag{3}$$

Then, substituting the pseudo inclinations of $I' = 0°$, 30°, 60° and 90° into Eq. (3), respectively, we obtain the corresponding RTP factors (thin solid line, dotted line, dashed line and thick solid line in Fig. 1, respectively). When $I' = 0°$, there is $H_{PI}(\theta) = H(\theta)$, i.e., the RTP factor is equivalent to that of the routine RTP method without suppression of amplification effects. When $I' > 0°$, the RTP factors suppress amplification in every direction to stabilize RTP. The larger the pseudo inclination (I') is, the stronger such suppression becomes. Extremely, when $I' = 90°$, there is $H_{PI}(\theta) = -1$, and the suppression reaches the maximum.

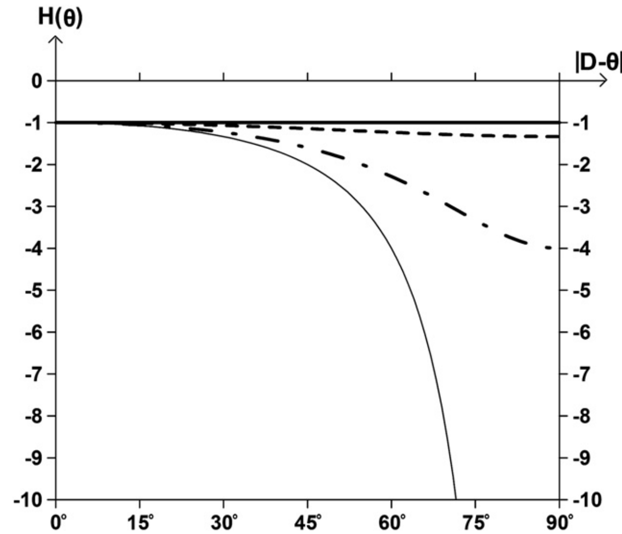

Fig. 1. The features of the RTP factor of the PI method at the magnetic equator. The thin solid line, dotted line, dashed line and thick solid line correspond to the pseudo inclination of 0°, 30°, 60° and 90°, respectively.

However, the RTP factor of the PI method suppresses the amplification effects not only along the magnetic declination but also in other directions. The suppression of other directions unexpectedly weakens the RTP characteristics and thus reduces RTP precision. To solve this problem, Li (2008) proposed an improved algorithm for the PI method, which uses the RTP factor of the PI method ($H_{PI}(\theta)$) to suppress amplification within a wedge-shaped segment centered along the magnetic declination, and uses the routine RTP factor ($H(\theta)$) in other directions to preserve amplification. Nevertheless, such an algorithm brings about the problem of discontinuity at the conjunction between the two different factors.

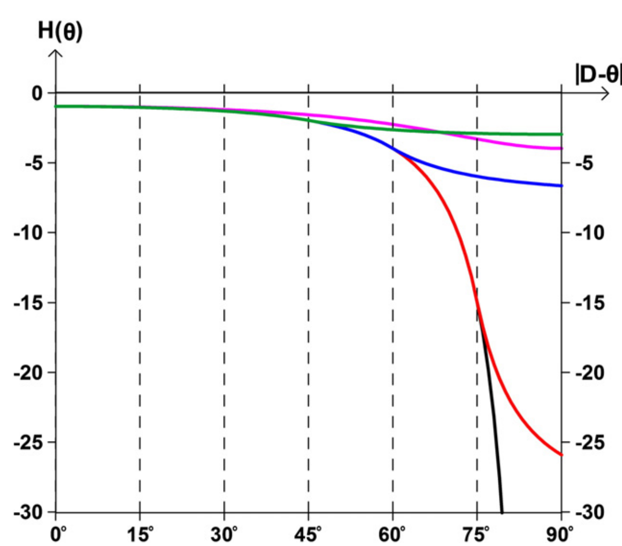

Fig. 2. The features of the RTP factor of the AF method at the magnetic equator. The black, red, blue and green lines correspond to the threshold angles of 90°, 75°, 60° and 45°, respectively. The purple curve is the RTP factor of the PI method with a pseudo inclination of 30°.