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Case study

A computationally efficient scheme for the inversion of large scale potential field data: Application to synthetic and real data

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ABSTRACT

Three dimensional (3D) inversion of potential field data from large scale surveys attempts to recover density or magnetic susceptibility distribution in the subspace for geological interpretation. It is computationally challenging and is not feasible on desktop computers. We propose an integrated scheme to address this problem. We adopt adaptive sampling to compress the dataset, and the cross curve of the data compression ratio and correlation coefficient between the initial and sampled data is used to choose the damping factor for adaptive sampling. Then, the conventional inversion algorithm in model space is transformed to data space, using the identity relationship between different matrices, which greatly reduces the memory requirement. Finally, parallel computation is employed to accelerate calculation of the kernel function. We use the conjugate gradient method to minimize the objective function and a damping factor is introduced to stabilize the iterative process. A wide variety of constraint options are also considered, such as depth weighing, sparseness, and boundary limits. We design a synthetic magnetic model with three prismatic susceptibility causative bodies to demonstrate the effectiveness of the proposed scheme. Tests on synthetic data show that the proposed scheme provides significant reduction in memory and time consumption, and the inversion result is reliable. These advantages hold true for practical field magnetic data from the Hawsons mining area in Australia, verifying the effectiveness of the proposed scheme.

1. Introduction

The potential field method has been playing an important role in various geologic and geophysical tasks. Rational inversion and interpretation of potential field data provide a view of the earth that highlights geological bodies, structures and boundaries (Nabighain et al., 2005a, b; Wang et al., 2014). For generalized inversion of potential field data, the three dimensional (3D) earth is discretized into cells with constant density, susceptibility, or a variant of the magnetization vector. A finite number of mathematical equations are formulated to recover the distribution of physical parameters in the subspace. Physical parameters of these cells outline geological bodies as well as geological structures (Yao et al., 2007; Guo et al., 2009; Meng et al., 2012). A variety of methods have been developed for 3D inversion of potential field data with both smooth and focusing regularizations (Li and Oldenburg, 1996, 1998, 2003; Hansen, 1998; Portniaguine and Zhdanov, 1999, 2002; Pilkington, 1997, 2009; Paoletti et al., 2013, 2014).

As exploration conditions deteriorate, higher resolution detections have become an inevitable trend. Thus, acquisition platforms collect dense datasets over large exploration regions. Inversion of dense field data (large scale field data) suffers from memory limitations and large processing time. More elaborate subdivision in model space makes this even worse. Various methods have been proposed to address these difficulties, including subspace methods (Oldenburg et al., 1993), matrix compression techniques (Li and Oldenburg, 2003), data space methods (Tarantola, 1987), etc. With subspace methods, the calculation is simplified to operations of a matrix with dimensions equal to the dimensionality of the subspace. The effectiveness of this method depends largely on the choice of the basic vector. Matrix compression methods sacrifice the resolution of the model space to speed calculation and reduce memory consumption. Data space methods enhance computational efficiency by dealing with an $N \times N$ system rather than an $M \times M$ one, where M is the number of model parameters, and N is

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the number of data points ($N < < M$). All of these methods provide some improvements for the inversion of large scale field data from one aspect or another. However, inversion of the entire dataset remains difficult when the dataset and number of model cells are very large.

We propose a general integrated computationally efficient scheme for the inversion of large scale potential field datasets on desktop computers, where the model domain can be discretized into hundreds of thousands (even millions) of cells. The scheme is comprised of three parts: data domain operations, model domain operations, and computational speed up. In Section 2, we briefly describe theory and steps of the data compression in data space and how to choose an appropriate damping factor. We provide a detailed derivation of the inversion algorithm in data space and incorporate parallel computation to speed up calculation. In Section 3, we present the inversion result from a synthetic magnetic model with the proposed scheme. The time and memory required are compared with conventional inversion techniques. In Section 4, we invert field magnetic data from Hawsons mining area in Australia to verify the effectiveness of our proposed scheme. Finally, we present our conclusions and indicate some directions for possible future work.

2. Description of the computation scheme

The proposed computation scheme consists of three parts, corresponding to different phases of the inversion process. We constructed a synthetic theoretical magnetic model to demonstrate the theory of the different operations. The synthetic model is consisted of three rectangular bodies with different sizes and susceptibility values, shown schematically in Fig 1a, b and c. The geometric and physical parameters of the model are shown in Table 1. We assumed there is no remnant magnetization and the demagnetization effect is negligible. Thus, only induced magnetization is considered. All causative sources are induced by a field with inclination 90°, declination 0°, and strength 50,000 nT. The corresponding magnetic responses of the synthetic models are contaminated by Gaussian noise with a standard deviation of 2% of the maximum anomaly value (Fig. 1d). The data domain is 64×64 km with data points located on a 0.1 km spaced uniform grid ($N = 409600$).

2.1. Operation in data space

The first part of the proposed scheme operates in the data domain. We use adaptive sampling technique to compress the

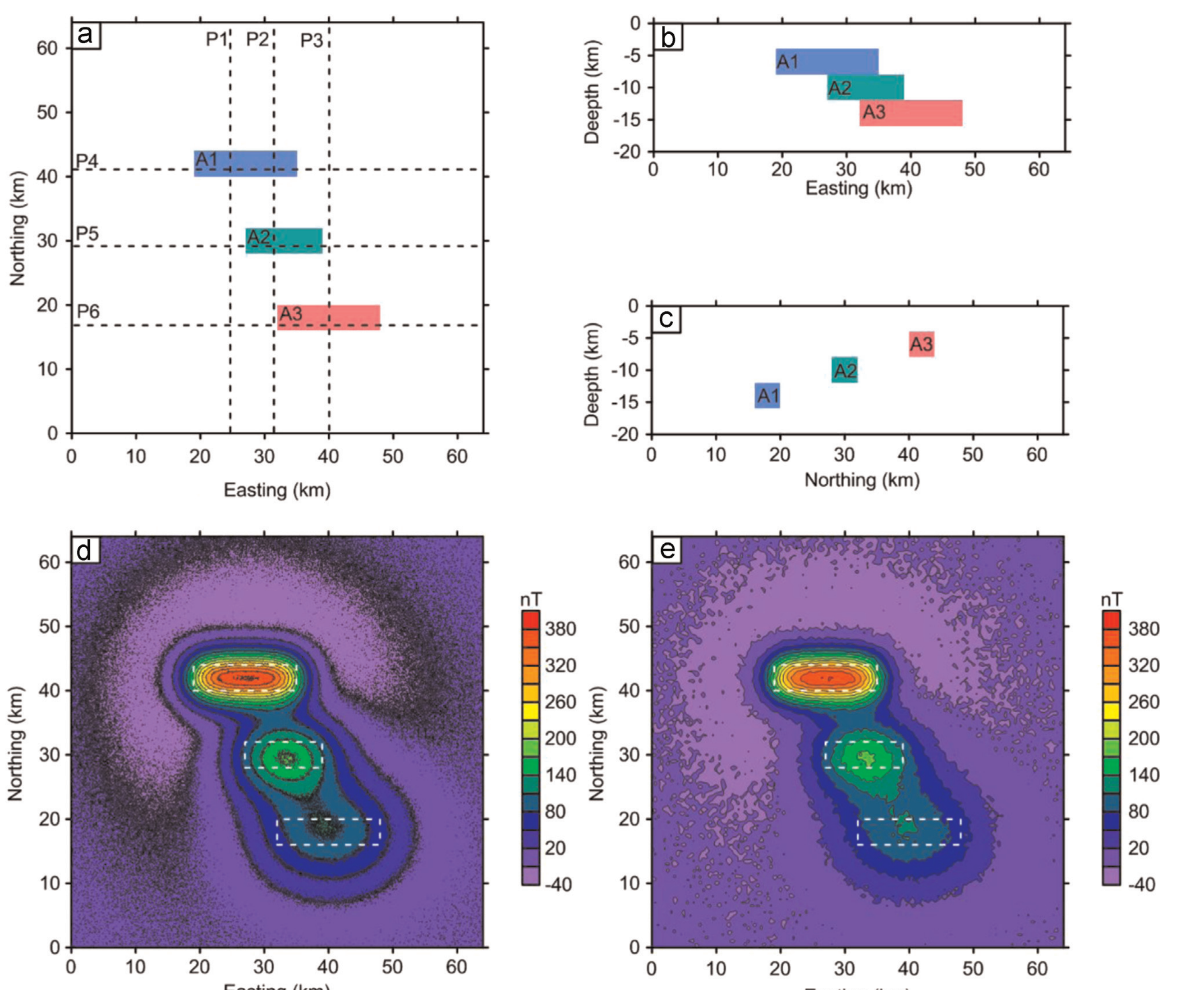

Fig. 1. Perspective views of the synthetic model and the theoretical magnetic anomaly produced by the model. A. Top view; b. Front view; c. Left view; d. Magnetic anomaly contaminated by Gaussian noise with a standard deviation of 2% of the maximum anomaly value; e. Magnetic anomaly produced by the recovered model.