Preliminary Study of Magnetic Anomaly Inversion using SimPEG Software and Single Anomaly Modeling

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Abstract

This research focuses on the use of gravity and magnetic technologies in geophysical exploration, which provides significant insights into the Earth's subsurface. Although these approaches may not equal the resolution of direct observations, they do give a quick, cost-effective, and non-invasive way of analyzing inaccessible areas and improving drill hole placements for future exploration. Gravity measurements identify differences induced by underlying density changes, making them indispensable for subsurface mapping and specialized geological research. Magnetic techniques, on the other hand, the oldest and most extensively used geophysical technique, capture anomalies in the Earth's magnetic field induced by horizontal magnetic property changes. In addition, the notion of inversion is explored, which is a mathematical approach that develops a subsurface physical property model by combining measured data and previous knowledge. The capacity of recovered models to adequately predict observed data determines their accuracy. By tackling the formulation and discretization of the geophysical forward issue, the suggested approach contributes to reducing the complexity of inverse modeling.

Introduction

Gravity and magnetic methods, which measure very small spatial and temporal changes in the terrestrial gravity and magnetic force fields, have a wide range of uses from submeter to global scales. Although these methods in most cases fail to match the resolution and precision of direct observations, they are rapid, cost-effective, and non-invasive procedures of studying the inaccessible Earth and optimizing the location of drill holes for direct studies and other remote sensing studies which have higher resolution capabilities (Hinze et al, 2013).

The gravity method of geophysical exploration is based on the measurement of variations in the gravity field caused by horizontal variations of density within the subsurface. It is an important technique for many problems that involve subsurface mapping, and it is the principal method in several specific types of geological studies (Hinze et al, 2013). The magnetic method is the oldest and one of the most widely used geophysical techniques for exploring the Earth’s subsurface. It is a relatively easy and inexpensive tool to apply to a wide variety of subsurface exploration problems involving horizontal magnetic property variations from near the base of the Earth’s crust to within the uppermost meter of soil. These variations cause anomalies in the Earth’s normal magnetic field that are mapped by the magnetic method (Hinze et al, 2013).

Inversion is defined as a mathematical technique that automatically constructs a subsurface physical property model from measured data by incorporating a priori information. The recovered models must predict measured data adequately (Foks et al., 2014). The solution to the inverse problem is dependent upon the formulation and discretization of the geophysical forward problem. Inverse modeling is decreased by using the proposed algorithm (Rezaie et al., 2017).

Included in SimPEG are staggered grids, mimetic finite volume discretization on several structured and semi-structured meshes, convex optimization programs, inversion routines, model parameterizations, useful utility codes, and interfaces to standard numerical solver packages. The framework and implementation are modular, allowing the user to explore, experiment with, and iterate over a variety of approaches to the inverse problem (Cockett et al, 2015).

SimPEG models using a variety of mesh structures, including Tensormesh and Octree. Tensormesh is a regular mesh that allows for the modeling of basic geometries, whereas Octree is an adaptable mesh that allows for the modeling of complicated geometries. Octree adaptive mesh can adjust mesh resolution and ensure computing efficiency in areas with high geometric complexity (Cockett et al, 2015).

The objective of this work was to carry out different types of modeling and inversions with different topographies.

Methodology

SimPEG includes a staggered grid and mimetic finite volume discretizations on structured and semi-structured meshes. It interfaces with standard numerical solver packages, convex optimization algorithms, model parameterizations, and visualization routines. We make use of Python's object-oriented paradigm leading to modular code that is extensible through inheritance and subtype polymorphism. SIMPEG follows a fully open-source development paradigm (Cockett et al, 2015).

The ability to carry out an inversion presupposes the ability to run a forward simulation and create predicted data given a physical property model. The forward simulation of resistivity data requires knowledge of the topography, the resistivity of the earth, and the survey details including locations of the current and potential electrodes, the source waveform, and the units of the observations (Cockett et al, 2015).

In the inverse problem, the first step is to specify how we parameterize the earth model. It is convenient to refer to the domain on which this model is discretized as the inversion mesh. The choice of discretization involves an assessment of the expected dimensionality of the earth model. The choice of discretization depends on the spatial distribution and resolution of the data and the expected complexity of the geologic setting (Cockett et al, 2015). We note that the inversion mesh has different design criteria and constraints than the forward simulation mesh.

To model the whole magnetic field anomaly in a certain location, the Forward Simulation of the whole Magnetic Intensity Data approach is employed. The total magnetic field anomaly is the discrepancy between the measured and predicted total magnetic field intensities at that site because of the subsurface magnetization of rocks.

The Sparse Norm Inversion for Total Magnetic Intensity Data on a Tensor Mesh approach, on the other hand, is used to invert the observed total magnetic field anomaly data to estimate the model parameters that best characterize the examined region's subsurface. This strategy employs a sparse regularization approach to guarantee that the resultant model is as basic as feasible, with minimal spatial fluctuations, while maintaining estimated quality.

The method is based on the construction of a tensor mesh model, which consists of a regular mesh of blocks with distinct physical characteristics. This enables a more exact and detailed subsurface depiction with better spatial resolution.

Sparse Norm Inversion for Total Magnetic Intensity Data on a Tensor Mesh is an accurate and efficient magnetic data inversion approach that allows for increased precision in subsurface modeling while reducing model complexity.

Results

To perform this work, we used three different topographies and a magnetic anomaly with a radius of 35 meters, which was the same in all three tests. All three models have an inclination of -36.8, a declination of -3.85, and magnetic field intensity of 50,000. Additionally, a plotting field of the magnetic anomaly image was used, ranging from -200 meters to 200 meters on the X and Y axes,

The dH, which represents the spacing between measurement samples along a profile or grid and is used to define the spatial resolution of the simulated data, was used with a value = 10.0 in all models.

Model 1:

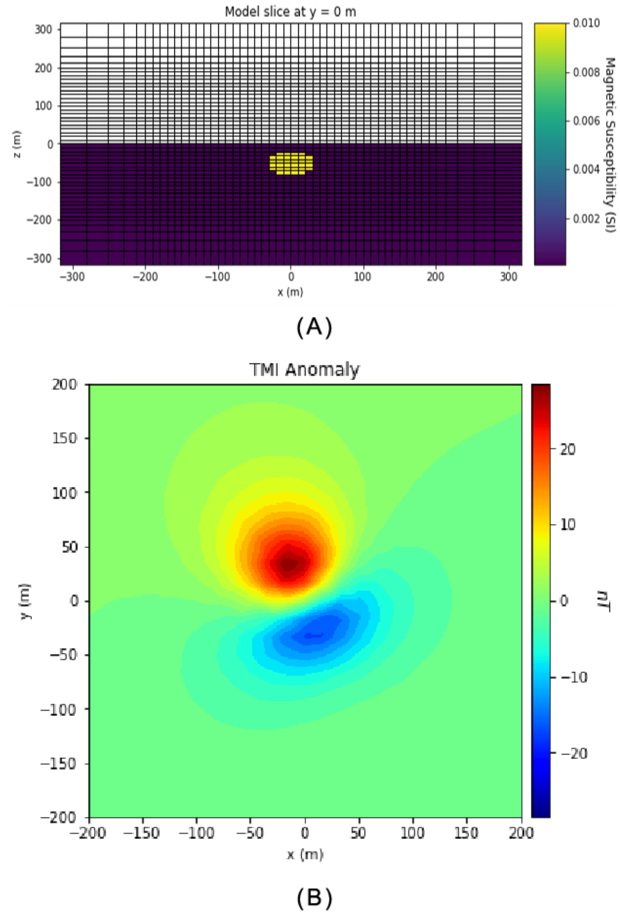


Figure 1: (A) Flat topography model; (B) Field generated by Flat topography model.

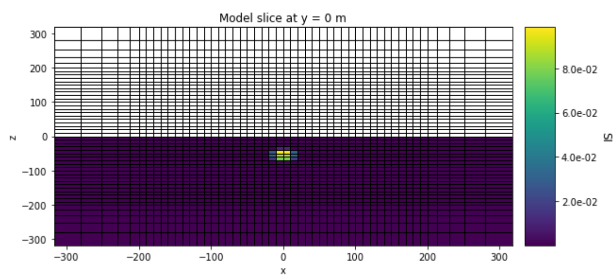
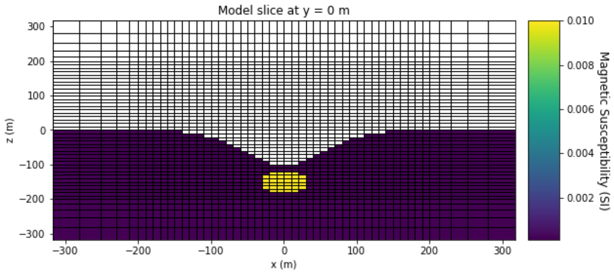


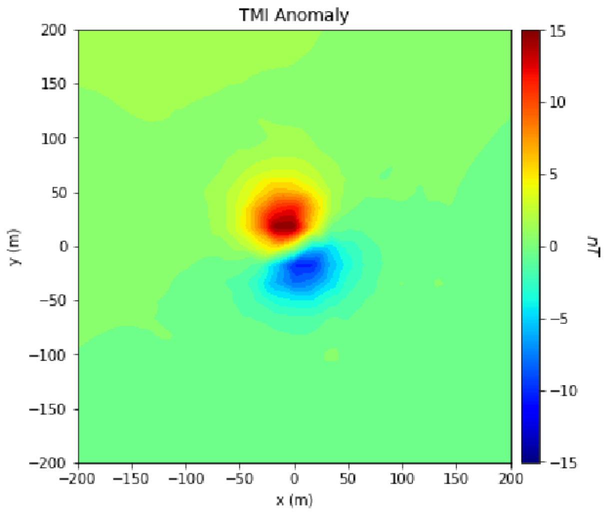
Figure 2: Model created from the inversion of Figure 1 (A)

From model (A) in Figure 1, the model presented in Figure 2 can partially recover the magnetic susceptibility (SI) and the shape of the body.

Model 2:



(A)



(B)

Figure 3: (A) Flat topography model; (B) Field generated by Flat topography model.

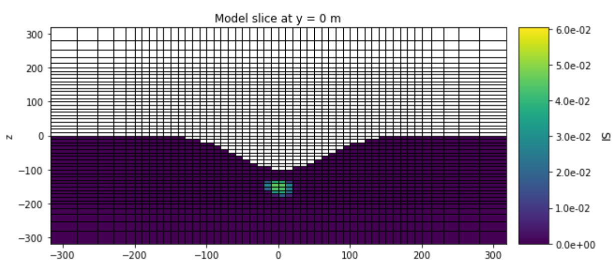
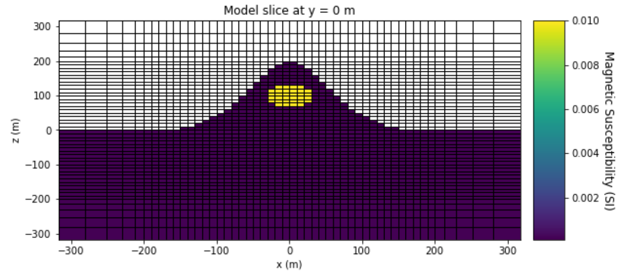


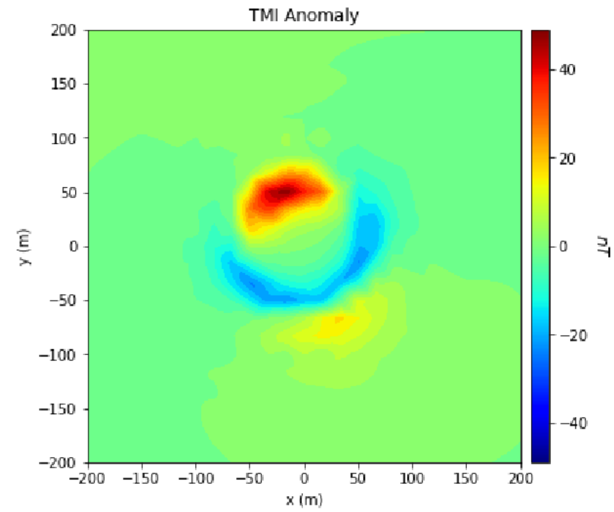
Figure 4: Model created from the inversion of Figure 3 (A).

From model (A) in Figure 3, the model presented in Figure 4 fails to recover the magnetic susceptibility (SI) and almost completely the shape of the body.

Model 3:



(A)



(B)

Figure 5: (A) Flat topography model; (B) Field generated by Flat topography model.

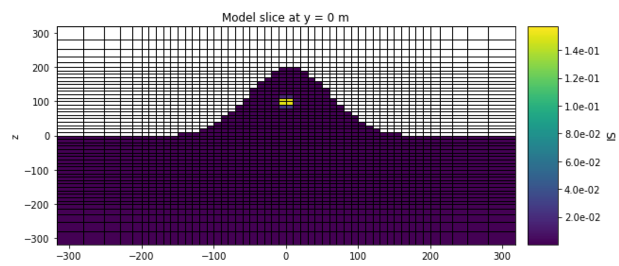


Figure 6: Model created from the inversion of Figure 5 (A).

From model (A) in Figure 5, the model presented in Figure 6 is able to recover the magnetic susceptibility (SI) but cannot fully recover the shape of the body.

Discussions

Figure 7 depicts the observed data, predicted data, and the misfit for whatever model. Because the mismatch is less than 20%, the findings show that the anticipated data is a decent approximation.

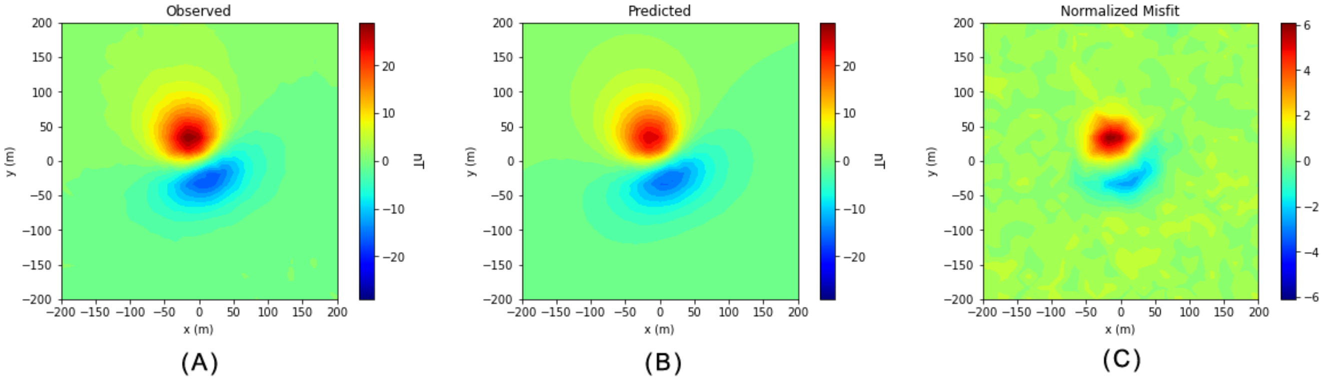


Figure 7: Result of magnetic field for Model 1; (A) Observed data generated by direct modeling in Figure 1; (B) Inverted magnetic field of Figure 2; (C) Difference between Observed (A) and Inverted (B) for Model 1.

Figure 8 represents the observed data, the predicted data, and the misfit. Presents the best result among the 3 models; however, it shows some numerical instabilities. Unfortunately, we do not know what they are at this moment; we need to perform more tests.

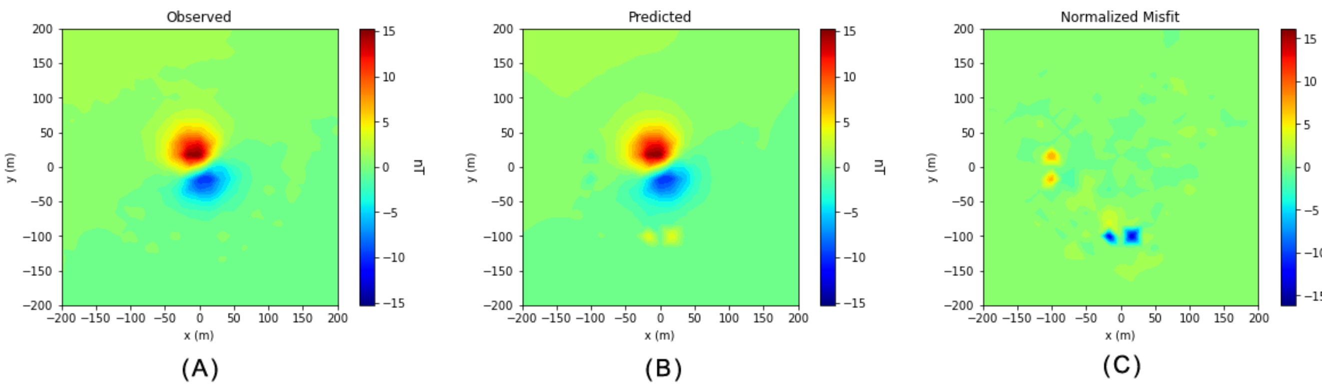


Figure 8: Result of magnetic field for Model 2; (A) Observed data generated by the direct modeling of Figure 3; (B) Inverted magnetic field of figure 3; (C) Difference between Observed (A) and Inverted (B) for Model 2.

Figure 9 represents the observed data, the predicted data, and the model's discrepancy. As the discrepancy is less than 15%, the results indicate that the data can achieve a considerable recovery from the initial model.

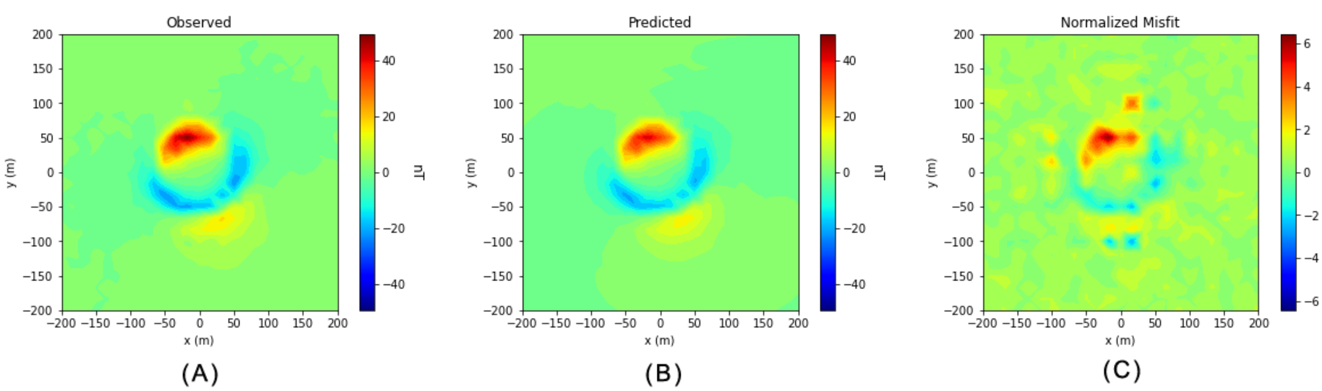


Figure 9: Result of magnetic field for Model 3; (A) Observed data generated by the direct modeling of Figure 5; (B) Inverted magnetic field of figure 5; (C) Difference between Observed (A) and Inverted (B) for Model 3.

Final considerations

According to the findings, the inversion method can recover the form and the magnetic susceptibility. Perhaps tweaking the anomaly position, changing the positive or negative height of the topography, or even changing the inclination and declination of the recorded data might resolve the recovery of magnetic susceptibility and body form in the model generated by the inversion.

Other aspects that may play a role include mesh size and receiver location, which may be erratic owing to mesh refining. This shows that the inversion's beginning circumstances are not optimally positioned.

The issue is presently being examined, and it is recommended that testing with finer meshes, enhancements, and improved receiver location be investigated.

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