Submission code: W4N60J8A4K

See this and other abstracts on our website: https://home.sbgf.org.br/Pages/resumos.php

Magnetic Inversion under Remanent Conditions with Directionally Constrained Modelling

Shayane Gonzalez, Tiago J. B. Sales, Wendel Moura, Saulo S. Martins (UFPA)

SBGf Conference 18-20 NOV | Rio'25

Magnetic Inversion under Remanent Conditions with Directionally Constrained Modelling

Abstract

Remanent magnetisation significantly affects magnetic inversion results, especially at low latitudes. This study presents a sequential workflow integrating Equivalent Layer (EL) direction estimation with constrained susceptibility inversion using the VOXI Earth Modelling platform. Synthetic models were used to assess the impact of remanence and validate the methodology. When incorrect or no remanent direction was assumed, inversions produced distorted geometries and underestimated susceptibilities. In contrast, using EL-estimated directions improved anomaly centering, reduced residuals, and more accurately recovered sources. Application of airborne magnetic data from Espírito Santo, Brazil, revealed a subhorizontal magnetic body with coherent geometry and a central high-susceptibility zone. The approach combines the directional robustness of EL with the 3D inversion capabilities of VOXI, offering a practical and stable solution for interpreting magnetic data affected by strong, coherent remanence. This method is especially valuable when conventional RTP or amplitude-only approaches fail.

Introduction

Magnetometry is a fundamental geophysical method for mapping subsurface structures based on variations in the Earth's magnetic field. It is widely used in mineral exploration, structural mapping, and environmental studies due to its high resolution and non-invasive nature (Blakely, 1995). However, remanent magnetisation, which is magnetism retained in rocks, often differs significantly from induced magnetisation in direction and intensity, particularly at low latitudes (Brown and McEnroe, 2011; Liu et al., 2020). This difference can severely distort magnetic anomaly shapes and amplitudes, hindering interpretation. Traditional inversion approaches, often relying on the assumption that total magnetisation aligns with the present-day geomagnetic field (e.g., for Reduction to the Pole - RTP), fail in the presence of significant remanence, leading to unreliable inversion outcomes and incorrect source geometry interpretations (Barbosa, 2021; Schmidt et al., 2014). To address these limitations, recent studies have explored techniques like Equivalent Layer (EL) methods to estimate the true direction of total magnetisation before inversion. This study presents a novel workflow integrating EL-based direction estimation with constrained susceptibility inversion, validated through synthetic models and real data (Gonzalez et al., 2020, 2022).

Method and Theory

This study employs the Equivalent Layer (EL) technique with a positivity constraint to estimate the total magnetisation direction under remanent conditions. The EL method replaces real sources with a planar distribution of dipoles at fixed depth, adjusted to reproduce the observed anomaly (Blakely, 1995; Reeves, 2005). Dipole moments are constrained to be positive, and the magnetisation direction is iteratively varied to best fit the data (Dampney, 1969; Reis et al., 2019, 2020).

The estimated direction is then incorporated into a 3-D magnetic susceptibility inversion using the VOXI Earth Modelling platform. This inversion aims to recover the spatial distribution of magnetic sources by fitting the total field anomaly. As an ill-posed problem, it is stabilised through regularisation techniques (Li and Oldenburg, 1996; Reeves, 2005). The model uses a regular mesh constrained by a digital elevation model (DEM), and iterative reweighting (IRI) is applied to enhance resolution and sharpness.

The proposed workflow consists of: (1) construction of synthetic models; (2) estimation of the total magnetisation direction using EL; (3) constrained susceptibility inversion in VOXI; and (4) validation with both synthetic and real datasets.

Results

Synthetic tests confirmed the effectiveness of the proposed methodology. In case A (induced-only scenario), RTP correctly centred the magnetic anomaly, and the inversion accurately recovered both geometry and susceptibility values (0.1 SI), with minimal residuals. In case B (remanence with incorrect direction), RTP failed to centre the anomaly. Although the inversion yielded a reasonable data fit, the recovered model was displaced, geometrically distorted, and displayed significantly underestimated susceptibilities (10^{-1}). In contrast, case C (remanence with EL-estimated direction) successfully repositioned the anomaly after direction estimation. The inversion produced a predicted field closely matching the observed data, with substantially reduced residuals compared to case B. The recovered geometry in case C was also notably closer to the true spherical model. However, the recovered volume remained slightly underestimated (Figure 1).

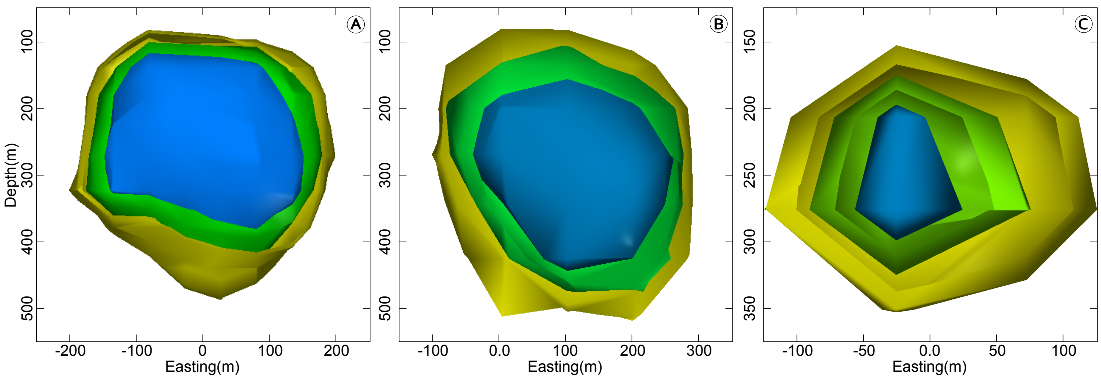

Figure 1: Recovered geometries for cases A, B, and C. Susceptibility thresholds clipped the models to highlight volume variations. Thresholds for cases A and C were 0.15, 0.10, and 0.05 SI; for case B, they were 0.015, 0.010, and 0.005 SI. Blue volumes indicate higher susceptibilities, yellow volumes lower ones.

Application to real airborne data from Espírito Santo (Brazil) involved RTP transformation using the EL-estimated magnetisation direction (18.56°, –61.16°). The VOXI inversion was executed on a 3-D mesh with cell dimensions of 250 × 250 × 125 m, constrained by a digital elevation model and using iterative reweighting (IRI) for sharpening. The inversion reached a final absolute data misfit of 10.85 nT. The resulting susceptibility model (Figure 2) delineates a moderately elongated, subhorizontal magnetic body with a westward dip at shallow to intermediate depths. The body extends approximately 3000 m in the E–W direction and 2000 m in the N–S direction, with a thickness exceeding 2500 m. Isosurfaces highlight a central zone of elevated susceptibility.

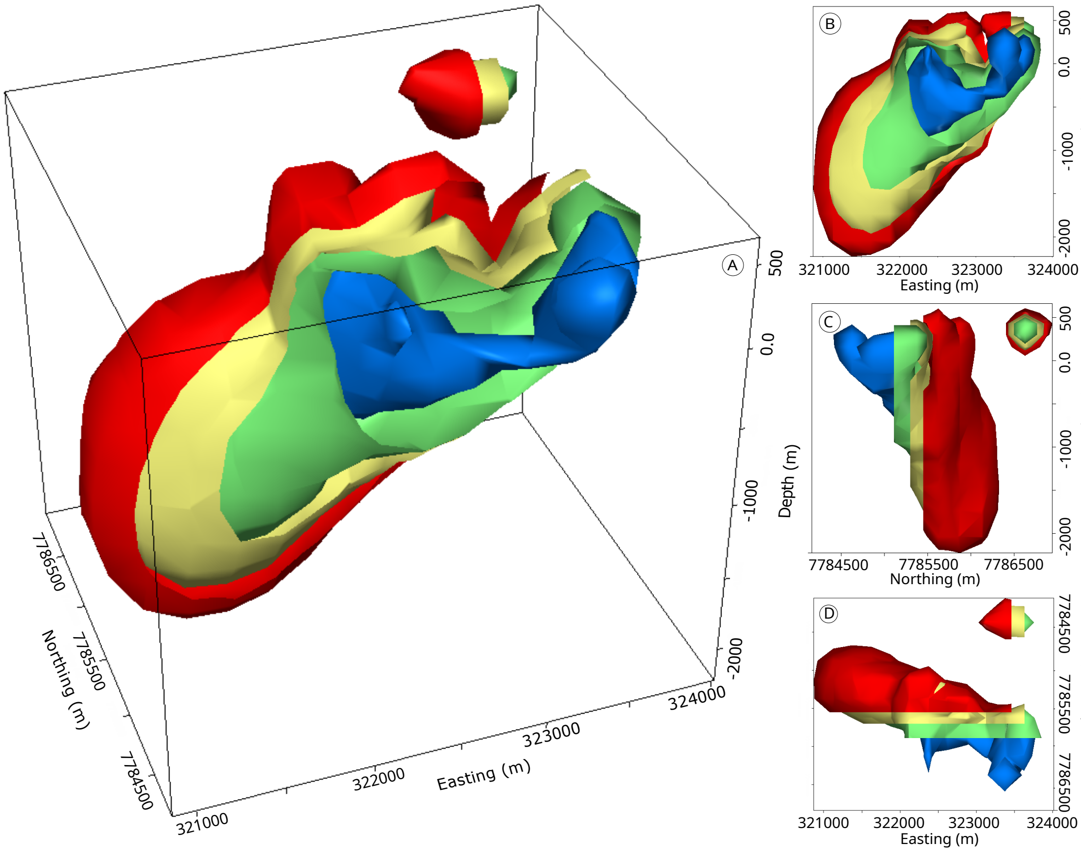

Figure 2: Three-dimensional susceptibility model recovered from the inversion of the RTP-transformed magnetic anomaly. Isosurfaces represent thresholds of 0.05, 0.10, 0.20, and 0.50 SI. Red volumes correspond to lower susceptibilities, and blue volumes correspond to higher ones. (A) Perspective view; (B) East-facing vertical section; (C) North-facing vertical section; (D) Plan view.

Conclusions

This study demonstrated the critical impact of remanent magnetisation on magnetic inversion and the necessity of accurately estimating the total magnetisation direction. Conventional methods, while sufficient in induced-only contexts, fail under remanent conditions, resulting in distorted geometries and underestimated susceptibilities.

The proposed sequential workflow—combining Equivalent Layer (EL) direction estimation with constrained VOXI susceptibility inversion—proved effective in synthetic and real data scenarios. The EL method enables robust direction estimation without assuming induced or remanent dominance, significantly improving inversion results. Compared to amplitude-only techniques, this integration retains full vector field information, enhancing interpretability. While Magnetic Vector Inversion (MVI) accounts for spatial variations, it may suffer from instability; in contrast, the uniform-direction approach used here provides stable and geologically consistent results for coherent remanence.

Application to airborne magnetic data from Espírito Santo, Brazil, corroborated the synthetic findings, delineating susceptibility structures aligned with the observed anomaly. Although the constant direction assumption may limit use in complex settings, the method offers a practical and reliable solution for many geological contexts. Future research may explore hybrid strategies to address spatially variable magnetisation directions.

References

Barbosa, R. D. d. L., 2021, Modelagem e inversão de dados potenciais da região do Parque dos Gaviões na Bacia do Parnaiba. (Accepted: 2023-02-16T19:17:04Z).

Blakely, R. J., 1995, Potential Theory in Gravity and Magnetic Applications, 1st edition ed.: Cambridge University Press.

Brown, L., and S. McEnroe, 2011, Remanent Magnetism, *in* Encyclopedia of Solid Earth Geophysics: Springer Netherlands, 1024–1030.

Dampney, C. N. G., 1969, The equivalent source technique: GEOPHYSICS, **34**, 39–53. (Publisher: Society of Exploration Geophysicists).

Gonzalez, S. P., V. C. F. Barbosa, and V. C. Oliveira, 2020, Estimate of the remanent magnetization direction via equivalent layer, *in* SEG Technical Program Expanded Abstracts 2020: Society of Exploration Geophysicists, SEG Technical Program Expanded Abstracts, 969–973.

Gonzalez, S. P., V. C. F. Barbosa, and V. C. Oliveira Jr., 2022, Analyzing the Ambiguity of the Remanent-Magnetization Direction Separated Into Induced and Remanent Magnetic Sources: Journal of Geophysical Research: Solid Earth, **127**, e2022JB024151. (_eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1029/2022JB024151).

Li, Y., and D. W. Oldenburg, 1996, 3-D inversion of magnetic data: Geophysics, **61**, 394–408. (Publisher: Society of Exploration Geophysicists).

Liu, S., X. Hu, B. Zuo, H. Zhang, M. Geng, Y. Ou, T. Yang, and S. Vatankhah, 2020, Susceptibility and remanent magnetization inversion of magnetic data with a priori information of the Köenigsberger ratio: Geophysical Journal International, **221**, 1090–1109.

Reeves, C., 2005, Aeromagnetic surveys: principles, practice and interpretation: Geosoft Washington (DC), **155**.

Reis, A. L. A., V. C. Oliveira, and V. C. F. Barbosa, 2019, Equivalent layer technique for estimating magnetization direction, *in* SEG Technical Program Expanded Abstracts 2019: Society of Exploration Geophysicists, SEG Technical Program Expanded Abstracts, 1769–1773.

Reis, A. L. A., V. C. Oliveira Jr., and V. C. F. Barbosa, 2020, Generalized positivity constraint on magnetic equivalent layers: GEOPHYSICS, **85**, J99–J110. (Publisher: Society of Exploration Geophysicists).

Schmidt, P. W., , and M. A. Lackie, 2014, Practical considerations: making measurements of susceptibility, remanence and Q in the field: Exploration Geophysics, **45**, 305–313. (Publisher: Taylor & Francis _eprint: https://doi.org/10.1071/EG14019).