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Editorial: Advances in geophysical inverse problems

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Editorial on the Research Topic
Advances in geophysical inverse problems

Introduction

Geophysical inverse problems face a lot of issues to be solved, e.g., data noise problems: the general data records contain a lot of noise due to various factors in the excitation, propagation and reception processes, and are generally band-limited, making it difficult to fully restore the true appearance of the model medium as the inversion results. The selection of the model: the real medium is often very complex, in order to facilitate the solution, generally we have to simplify the physical equations, this simplification will inevitably bring model errors leading to difficulty in practical applications. Ill-posed nature: the inversion process is a complex nonlinear problem, and the actual inverse problems are ill-posed, as well as the empirical selection of the initial guess of the solution, causing multiple solutions and low resolution of the inversion result. Large scale computing: the media model in the actual calculation is very large, and it is usually necessary to implement numerical discretization of the original continuous problem and carry out finite dimensional approximation. Due to the dimensionality effect, we need to solve a large algebraic systems of equations, which leads to a huge amount of computation and storage for solving ill-posed nonlinear problems.

Collected contributions

There are six contributions in this edited volume, covering multiple aspects of geophysical exploration from different scale.

1. The gravity inversion with sparsity constraint is an effective technique for recovering the density distribution of subsurface blocks, and is widely used for quantitative interpretation of gravity data. To avoid updating the sparsity reweighted function, a projected method based on adaptive Lanczos bidiagonalization is proposed. This method only requires calculating the reweighted forward matrix and Lanczos bidiagonalization matrix once, which significantly reduces the computational complexity.

2. Accurate inversion of seismic fault parameters has been a challenge in the studies of geophysical non-linear inversion problems. Many non-linear methods such as Simulated Annealing (SA), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Multipeaks Particle Swarm Optimization (MPSO), have usually been applied to inverse the fault parameters from geodetic observation data. A new non-linear method Black Hole Particle Swarm Optimization (BHPSO) is proposed, to inverse fault parameters of different-type earthquakes from synthetic and observed GPS and InSAR data. Five geophysical inversion methods (SA, GA, PSO, MPSO, and BHPSO) are compared. It is found that the MPSO and BHPSO performed better than SA, GA, and PSO for inversion from both the synthetic and observed data, and the new inversion method, BHPSO, can be used for seismic fault parameter inversion, and it has high accuracy in fault parameter inversion.
3. For nano-scale imaging of shale, a phase retrieval model based on transport-of-intensity equation (TIE) in space domain is established. During solution of the TIE equation, due to the discretization of differential operators leading to the instability of the problem, the regularization technique is employed, and a posterior regularization method in space domain is proposed for solving the phase retrieval problem, meanwhile selection of an optimal posterior regularization parameter is adopted, which accelerates the convergence speed of the iterations. The study shows that relative errors of the proposed method are nearly 1% of that of the traditional method based on frequency domain, and hence the method is promising for the practical data processing.
4. For joint inversion of multiphysics data, the Gramian defined as the determinant of the Gram matrix formed by models of different physical properties of the geologic formations (e.g., density, electrical conductivity, seismic velocity, magnetization, etc.) is incorporated as the constraint. In computation, a probabilistic approach is applied, which provides insight into the properties of the inversion and helps improve the reliability of the inversion results. Gaussian processes, Bayesian statistics, and empirical Bayes paired with rapidly advancing joint inversion strategies present a promising future for multi-modal geophysical inversion.
5. The traditional impedance inversion method cannot fully exploit the sparse characteristics of geological attributes. A data-driven acoustic impedance inversion method with a reweighted L1 norm served as a sparse constraint (RL1) is proposed. The RL1 replaces the traditional inversion method which is constrained by the L1 norm. The RL1 method can describe more sparsity information and improve the resolution of inversion. To enhance the stability and accuracy of seismic inversion, local cross-correlation analysis is incorporated. This analysis assesses the suitability of each sampling point in the seismic data, regulating their impact on the inversion process. The alternating direction method of multipliers and soft threshold shrinkage algorithm are employed to solve the inversion objective function. This approach ensures more robust and precise inversion results.
6. Due to the diffusive character of the EM field, only very low frequencies are used leading to inversion results with rather low resolution. Calculation of the resolution matrix associated with the inversion is proposed and the corresponding Point Spread Functions (PSFs) is derived. The PSFs give information about how much the actual inversion has been blurred, and use of space-varying deconvolution can therefore further improve the inversion result. Feasibility of applying deblurring as a post-processing technique can enhance the resolution of the model output from CSEM inversion. In realization, a portfolio of supporting software that makes it possible to extract the model resolution matrix associated with a CSEM inversion is developed and the corresponding blur matrix is built which can be used to correct for the blur described by the space-invariant PSFs. The actual deblurring is carried out by use of the Non-Negative Flexible Gradient Least-Squares (NN-FCGLS) algorithm. Applications on both synthetic and field data demonstrated the potential of the proposed approach.

Conclusion

In this Research Topic, we focus on computational methods for geophysical inverse problems, the topic includes gravity inversion, statistical inversion for fault parameters, nano-scale imaging of shale, seismic impedance inversion, EM inversion and geophysical joint inversion. Novel methodologies and applications are introduced from different point of view.

Author contributions

YW: Methodology, Writing–original draft, Writing–review and editing. AY: Methodology, Writing–review and editing. LG: Methodology, Writing–review and editing.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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