Joint inversion of magnetotelluric data and receiver functions using Pareto-based swarm intelligence algorithm

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SUMMARY

The increasing popularity in joint inversion could be attributed to the successful determination of structures that are difficult to detect by restricting the models using priori information in conventional modelling. In recent years, joint inversion of magneto-telluric data and receiver functions also provides valuable information on structures extending from the upper crust to the lower crust such as detached and folded metamorphic complex structures, weakly layered crust, etc. Another well-known disadvantages of the derivative-based conventional modeling algorithms used to determine these structures is that the solution has a dependency to an initial model and the possibility of trapping in a local minimum.

The seismic velocity and electrical conductivity parameters solved with the inversion of receiver function and magnetotelluric data are not well correlated physically, and jointly inverting them in the scientific literature is generally used in two ways: 1) to obtain a solution with the empirical relationships extracted from the laboratory experiments, the so-called petrophysical approach, 2) the cross-gradient approach, which aims to obtain a solution using structural constraints. Since the relationship between seismic velocities and conductivity is largely unknown in the petrophysical approach, a weak coupling between them increases the resolution but can also lead to misleading and incorrect results. These physical parameters can have different responses to the inputs such as porosity, permeability, temperature. As a commonly accepted approach, the cross-gradient method looks for the solution having structural similarities between the two models. However, the two different datasets does not always respond to the structural similarities equally, thus obtaining more convincing solution may involve the consideration of different structural couplings with a regularization term added to the objective function as a multiplier or a weighted sum.

In this study, Particle Swarm Optimization integrated with the Pareto optimality approach (Pareto-PSO) applied to the receiver function and magnetotelluric data to jointly invert them. PSO is a metaheuristic global optimization algorithm inspired by the social behavior of flocks of birds or fish, and is an excellent alternative to traditional geophysical modeling techniques that suffer from initial model dependence, linearization problems, and trapping at a local minimum. Pareto-PSO also provides the opportunity to model in a joint system without reducing the resolution of individual datasets that have different physical sensitivities. Similar to the cross-gradient approach in modeling receiver functions and magnetotelluric data that provide one-dimensional model responses, this study examines the gradient approach in the vertical direction only. By using the advantage of the Pareto approach, apart from the classical weighted sum approach in the objective function, the structural differences have been added to the objective function space as a third axis alongside the misfit of the receiver function and magnetotelluric data to search for the solution without the need for weighting and combining in the objective function.

We tested a series of synthetic models containing noise-free and noisy data of the magnetotelluric and receiver functions by using Pareto-PSO. Since the seismic velocity and electrical conductivity parameters may indicate different responses to the same physical phenomena, the variation of the parameters was applied in the same direction but with different percentages. Our modeling approach is successfully solved the structures by using the Pareto front, which presents the joint and individual solutions for the two datasets, also allows to analyze the non-uniqueness of the solution from the Pareto-front solutions.