A new method for 2D stochastic inverse modeling in Magnetotellurics: application to the Larderello-Travale geothermal field and novel results from 3D inversion

A new method for 2D stochastic inverse modeling in Magnetotellurics: application to the Larderello-Travale geothermal field and novel results from 3D inversion

Summary

The magnetotelluric method (MT) is one of the most effective geophysical techniques for the investigation of deep geothermal systems because it can recover the electrical-resistivity distribution of the Earth from a few meters to hundreds of kilometers of depth.

The MT inverse problem is ill-posed in nature with nonlinear and equivalent solutions. The standard approach to solve the inverse problem is the iterated and linearized inversion. However, it is also possible to adopt the global search approach, which performs stochastic inverse modeling by adopting the Monte-Carlo or metaheuristic methods. Global search methods have become of major interest in geophysics because they are theoretically able to find the global minimum of a function as the final solution without being trapped in one of the several local minima. The potential advantages of metaheuristics are also to provide complete sampling of the search space of solutions and independence from the starting model.

The development of a metaheuristic method to solve the 2D MT inverse problem represents a novelty in the framework of the existing MT inversion techniques. Moreover, deploying 2D stochastic inverse modeling to interpret MT data from geothermal areas has a great potential, mostly in those cases where the geological complexity and the difficulty in retrieving reliable external constraints can negatively affect the solution of the inverse problem. One of the most extraordinary geothermal resources in the world is the Larderello-Travale geothermal area (LTGA), located in south Tuscany, Italy. The area has been the object of vast industrial and scientific research over the past century. Nonetheless, some geological, physical and chemical aspects are still a matter of research.

This thesis investigates a new method, based on particle swarm optimization (PSO), to perform stochastic inverse modeling of 2D MT data. The PSO input parameters were accurately calibrated by means of a sensitivity analysis in order to enhance the stability and convergence of the solution. The computationally demanding nature of the algorithm was overcome by parallelizing the code to be run on a High Performance Computing (HPC) cluster. PSO was applied to two examples of MT synthetic data of different complexity. The PSO was initialized both by giving a priori information and by using a random initialization. The a priori information was given to a small number of particles, i.e., selected models, as the initial position, so that the swarming behavior was only slightly influenced. We demonstrated that there is no need for the a priori initialization to obtain robust 2D models because the results were largely comparable with the results from randomly initialized PSO. After this validation, the method was applied to the MT benchmark for real-field data, the COPROD2 data set (Canada). PSO of COPROD2 data provided a resistivity model of the earth in line with results from previous interpretations. The stochastic nature of PSO and the combination of exploration and exploitation behaviors played a key role in finding the global minimum of the search space as final solution.

The PSO algorithm was also applied to two MT profiles located in the LTGA. For the first time, MT data from this geothermal area have been 2D interpreted using a metaheuristic method. The final models succeeded in imaging very complex resistivity structures similar to those presented in previous research, but with the following advantages: (i) the final models have not been initially biased by an external starting model derived from geology and (ii) the RMSEs associated to the final PSO models were lower than those associated to the models obtained by different inversion techniques.

Furthermore, 3D MT inversion is currently an area of very intensive research and no work to date has focused on 3D inversion of MT data from the Travale geothermal area. The MT data that have been acquired in Travale during the past decades were recovered and accurately analyzed to determine the geoelectrical dimensionality and directionality, strike direction and phase tensor properties. Static shift was corrected through new time-domain electromagnetic (TDEM) measurements. A number of 3D MT inversion tests were performed by changing the grid rotation, error floor and starting model in order to assess the connection between the inversion response and geology. The final 3D model was compared with other subsurface data and models. To the best of the authors' knowledge, this is the first 3D resistivity model of the Travale geothermal system derived from complete MT inversion. The outcome of this study provides new insight into the interpretation of the complex geothermal system of Travale.