METHOD DEVELOPMENTS IN GEOPHYSICAL INVERSION

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Introduction

The development of computer science broke a new path in engineering technology. The improved capacity and speed of computers facilitated to treat such complex geophysical problems that could not have been solved before. The theoretical and practical issues of geophysical information processing or geophysical inversion have been increasing in the last decades. These researches apply the methods of optimization theory and computer science implementing them in solving various kinds of geophysical inverse problems.

The solution of the inverse problem (i.e. inverse modeling) requires preliminary knowledge on the geological structure. A decision must be made both on the type of the model (e.g. horizontally layered, dipped or tectonic structure, 2D or 3D, etc.) and its approximate (petrophysical and geometrical) model properties are to be assumed. This need, on one hand, a priori geological and geophysical knowledge about the investigated geological structure and, on the other hand, appreciable computational (hardware and software) facilities. The latter is of great importance in calculating the theoretical responses (i.e. calculated data) over complex structures by using proper physical principles and sophisticated numerical methods. The problem of data prediction is called also forward modeling, in which data are calculated by known/assumed values of the model parameters. These calculated data are then compared to real (field) data measured over the geological structure in the required measurement arrays. The data misfit is characterized by an objective function, which is minimized by using an optimization algorithm. The initial model is progressively refined in an iteration procedure until a proper fit is achieved between the predictions and observations.

In this lecture we give an overview on the backgrounds of geophysical inverse problems and show those special tools that leads to more reliable and accurate estimate of petrophysical and structural properties of geological structures.

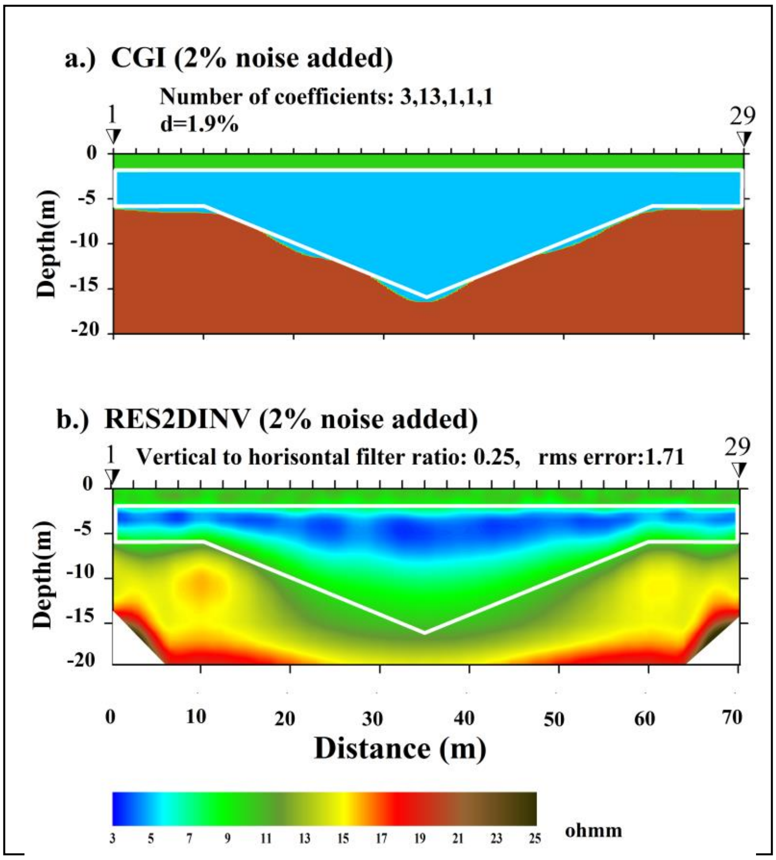
Samples and methods

In most of the cases the number of measured data exceeds the number of unknown model parameters that means, we deal with overdetermined inverse problem giving parameter estimation influenced by a number of factors acting in both data and model spaces. The measurement data are always contaminated by randomly distributed noise. Solving the inverse problem, the data noise also will be mapped into the model space. Robust/resistant inversion methods are developed in order to find acceptable parameter estimation independently from the noise distribution. There can arise uniqueness problems in solving the inverse problem when the data set doesn’t contain information enough to determine all of the unknown model parameters (partially underdetermined or mix-determined problem). To find unique solution new sources of information should be involved in a joint inversion procedure (Dobróka et al. 1991). The new information can arise from data set of different physical nature (for example seismic-geoelectric joint inversion) or from data of the same nature measured in geometrically different kind of arrays.

To solve the inverse problem an adequate objective function is defined, which is minimized during the optimization procedure. In most cases it is based on the L2-norm of the difference between the measured and calculated data. More robust parameter estimation is given by minimizing L1 or other weighted norms using Cauchy or Steiner weights. The optimization method can be selected from a broad collection of linearized or global procedures. The calculated data are produced in the framework of the forward modelling. In applying a proper forward modelling algorithm, a tradeoff should be taken between computational accuracy and computational cost. In case of real 2D or 3D geological model the forward modeling is typically solved by the use of finite difference or finite element methods which are time consuming. In these methods during discretization of the model a mesh is defined containing elements of the order of 10^5-10^6. In solving the forward problem, the model parameters should be given in these mesh points resulting in the same number of unknowns in solving the inverse problem. Having some hundred or thousand measured data the 2D or 3D inverse problem is hardly underdetermined at this point. In order to find unique solutions additional conditions are to be involved. These (usually non-physical) requirements results in a smooth geological model as a solution of the inverse problem. The method of series expansion based inversion leads us back to an overdetermined inverse problem. In this procedure – as a useful kind of discretization- the space-dependent model parameters are expanded in series by appropriately chosen orthogonal set of base functions. The inverse problem is defined in terms of the expansion coefficients.

Results

Series expansion based inversion method was successfully used in the interpretation of geoelectric (Gyulai et al. 2010), electromagnetic (Turai, 2011) and borehole geophysical data (Szabó N. P., 2011). As an example a geoelectric application is shown in Fig. 1.



The model contains three homogeneous layers (the exact boundaries are shown by white lines). The first (green) layer boundary is horizontal, the second (blue) one shows 2D geometry. The third (brown) layer is an infinite half space. The apparent resistivity values of the 29 VES measurement lines (perpendicular to the plane of the figure) were calculated by means of 3D Finite Difference method. The data were contaminated by 2% Gaussian noise.

The figure shows a comparison between the results of series expansion based inversion and those given by RES2DINV, which is one of the most frequently used 2D inversion software in the international practice. (It solves underdetermined inverse problem with additional smoothing conditions.) It can be seen that RES2DINV gives highly smoothed result.

a.) result of the series expansion based inversion (19 expansion coefficients were used, the fitting error: 1.9%).

b.) result of RES2DINV using vertical to horizontal filter ratio of 0.25.

Figure 1. *Comparison of inversion results of 2D noisy synthetic data.*

References

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