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A template for 1-D inversion of geo-electromagnetic data using Markov Chain Monte Carlo (MCMC) method

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Introduction

For most of researchers in geo-electromagnetism, 1-D modeling of geo-electromagnetic data (MT, CSAMT, VES, etc.) can be considered as a solved problem. However, non-linearity of the problem, ambiguity or non-uniqueness and other aspects are still there for further study (e.g. Guo et al., 2011; Sharma & Verma, 2011). In addition, 1-D approximation of the medium of the subsurface is considered valid in many situations, data types and also data availability, e.g. reconnaissance studies, sparse VES data, airborne EM etc.

This paper describes a 1-D inversion modeling of vertical electrical sounding (VES) data using Schlumberger array. The algorithm employs Markov Chain Monte Carlo (MCMC) previously applied to 1-D inversion of MT data (Grandis et al., 1999). The algorithm was tested to invert synthetic data corresponding to simple three-layer models. The method was also applied to field VES data acquired on a profile. The data were interpolated laterally resulting in denser data coverage and the inverse models were concatenated one to the other to obtain a quasi 2-D model. The model showed satisfactory agreement with 2-D inversion result. The algorithm is quite generic such that it can be used as a template to invert other geo-electromagnetic data (e.g. CSAMT, SNMR etc.) for 1-D modeling.

The Algorithm

In this paper we will only describe the practical aspects of the MCMC algorithm. The readers are referred to Grandis et al. (1999) for the theoretical background of the method. Consider a 1-D model formed by a number of layers with thickness h_i and resistivities ρ_i, i = 1, 2, ..., NL where NL is the number of layers. For a large number of layers (20 or more) with fixed thicknesses, the model parameters to be estimated in the inversion are layers' resistivities. The possible values for resistivities are discrete values R_j; j = 1, 2, ..., M representing conductive to resistive medium (i.e. logarithmically sampled from 0.1 to 1000 Ohm.m). The probability of R_j as the resistivity of the i -th layer ρ_i can be expressed by:

$$P(R_j) = \exp(-E(\mathbf{m} \mid \rho_i = R_j)) \quad (1)$$

where $E(\mathbf{m}|\rho_i = R_j)$ is the misfit related to a model **m** in which $\rho_i = R_j$ while resistivities of layers other than *i*-th layer are fixed at their current values. In case of VES data using Schlumberger array, the Gosh-Koefoed filters (Ekinci & Demirci, 2008) were employed to calculate the respons of 1-D model, i.e. apparent resistivity as function of electrode spacings (*AB*/2).

Starting with a homogeneous model, the iterative refinement of the model proceeds by choosing randomly the resistivity of a layer from R_j; j = 1, 2, ..., M with the probability in equation (1) as weights. A resisitivity value for a particular layer has higher probability if it is associated with lower misfit. The equation (1) is in fact equivalent to the transition probability of a Markov chain stating that the probability of a future state (or model) depends on all previous states only through the present state, i.e. most recent state. The MCMC algorithm samples the model space favouring regions where solutions are likely exist. It belongs to a class of computer intensive methods since a large number of misfit calculations must be performed in the estimation of the transition or weighting probability. However, for a simple 1-D forward modeling in VES or other geo-electrical methods and with the advent of current computational resources, the calculations can still be amenable.

Results

Due to equivalence problems, models with high variation in resistivities from layer to layer may result in near-optimal misfit. Therefore, additional constrain other than misfit is introduced, i.e. model smoothness. The convergence to optimal model is encouraging as shown in Figure 1 for inversions of synthetic data associated with simple three-layer models.

The inverse models are moderately smoothed (see Figure 1), leading to the idea of presenting the result of inversion of VES data along a profile in a contour plot to give a quasi 2-D model. For that purpose the field VES data along a profile with the station spacing of approximately 300 to 400 m were laterally interpolated to result in a more regular VES data at every 100 m. We follow the idea of Ris et al. (2010) in using the Krigging method in the VES data interpolation. The inversion results (after contouring) are presented in Figure 2. The geological implication of the result is beyond the scope of this paper.

The quasi 2-D model is compared to the result of 2-D inversion of the same data by using RES2DINV software (Loke, 2004). In this case, VES data were interpolated to obtain data appropriate for 2-D inversion, i.e. Wenner-Schlumberger array similar to the technique used by Ris et al. (2010). Both results are equivalent, although only quasi 2-D model is shown in this paper for the sake of brevity.

Conclusion

The 1-D inversion method using Markov Chain Monte Carlo (MCMC) algorithm developed previously for MT data has been adapted for VES data. Having similar characteristics, straightforward approach may be applied to other geo-electromagnetic data (CSAMT, SNMR, AEM etc.) for 1-D modeling. With the progress in computational hardware, the inversion of a series of data along a profile can be performed in a reasonable execution time to produce a quasi 2-D model usually obtained from approximate or data transformation methods.

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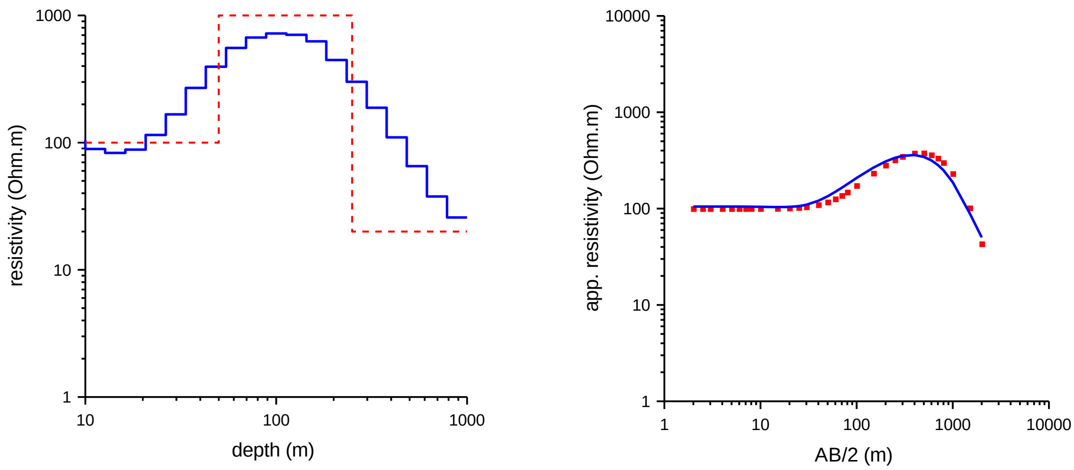

Fig. 1a: Smoothed inverse model compared to blocky syntheticmodel (left) and data fit (right).

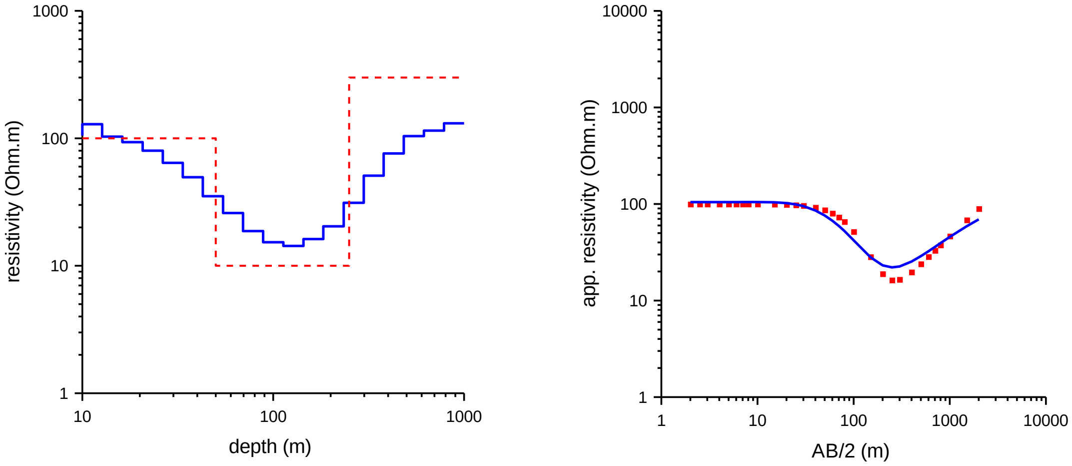

Fig. 1b: Smoothed inverse model compared to blocky syntheticmodel (left) and data fit (right).

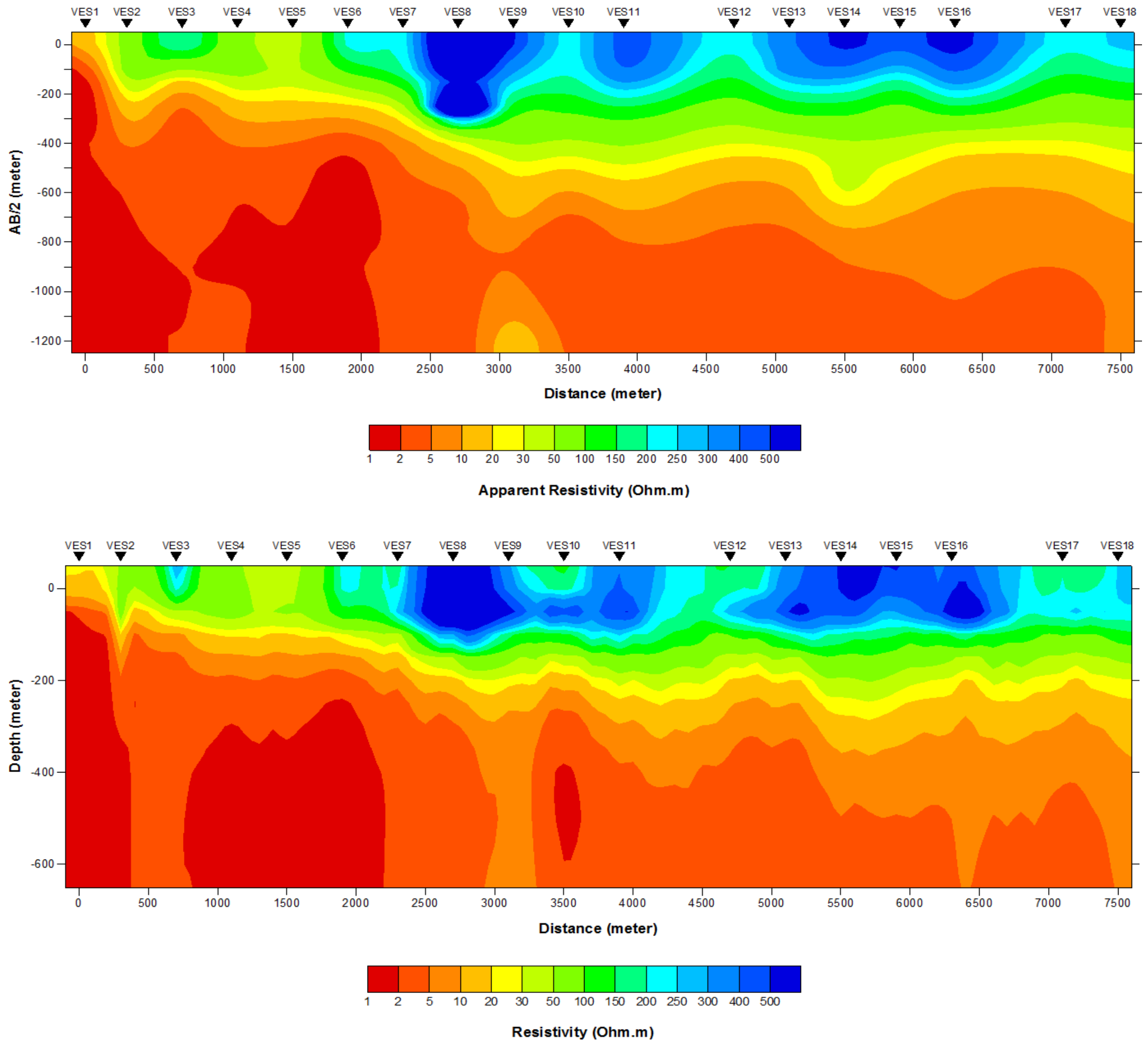

Fig. 2: Result of field VES data inversion, observed apparent resistivity pseudo-section (top) and quasi 2-D model (bottom).