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Estimating depth of investigation in dc resistivity and IP surveys

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ABSTRACT

In this paper, the term "depth of investigation" refers generically to the depth below which surface data are insensitive to the value of the physical property of the earth. Estimates of this depth for dc resistivity and induced polarization (IP) surveys are essential when interpreting models obtained from any inversion because structure beneath that depth should not be interpreted geologically. We advocate carrying out a limited exploration of model space to generate a few models that have minimum structure and that differ substantially from the final model used for interpretation. Visual assessment of these models often provides answers about existence of deeper structures. Differences between the models can be quantified into a depth of investigation (DOI) index that can be displayed with the model used for interpretation. An explicit algorithm for evaluating the DOI is presented. The DOI curves are somewhat dependent upon the parameters used to generate the different models, but the results are robust enough to provide the user with a first-order estimate of a depth region below which the earth structure is no longer constrained by the data. This prevents overinterpretation of the inversion results. The DOI analysis reaffirms the generally accepted conclusions that different electrode array geometries have different depths of penetration. However, the differences between the inverted models for different electrode arrays are far less than differences in the pseudosection images. Field data from the Century deposit are inverted and presented with their DOI index.

INTRODUCTION

In a dc resistivity or induced polarization (IP) survey we are generally provided with data d (apparent resistivity or apparent chargeability) and an estimate of their errors. An inverse problem is then solved to find the model m (conductivity or chargeability) that generated the data. It is recognized that the inverse problem is nonunique, and modern strategies cope with this by using optimization techniques. Let ϕ_m be a functional of the model and let ϕ_d denote the misfit functional. The optimization problem is solved by finding a specific model m^* that minimizes ϕ_m subject to $\phi_d = \phi_d^*$, where ϕ_d^* is a target misfit. The nature of the constructed model is determined by ϕ_m, and much effort is required to tailor this functional so that m^* is interpretable, has the right "character," and is consistent with a priori knowledge about the earth. The amount of structure in m^* is determined by how well the observed data are reproduced. Generally, increasing the fit to the data requires more structure. When the minimization is complete, m^* is our best estimate of the true earth model, and it is from that image that we want to make geophysical and geological inferences. When viewing this image however, there are numerous questions that arise: (1) Which features in the recovered model emulate those in the true earth? (2) What confidence do we have in the existence of the features? (3) What is the level of detail that can be responsibly inferred? (4) Are there artifacts at depth, which if interpreted, would lead to misleading interpretations?

These questions are interrelated, but this paper focuses on artifacts at depth. Surface potentials measured in dc resistivity and IP surveys are sensitive to conductivity and chargeability only in a region in the vicinity of the electrode array. Yet when the data are inverted, it is necessary to consider a mathematical model that extends outwards from the survey area and to great depths. The boundaries are determined by the finite difference mesh used to carry out forward modeling, and they must be sufficiently far from the survey area so that imposed approximate boundary conditions do not cause numerical artifacts in the forward modeling. Because the recovered conductivity or chargeability extends to these boundaries, it is not known whether features observed at great depth are demanded by the data or if they are artifacts associated with the model objective function that is minimized.

To motivate our analysis, consider an attempt to recover a 2-D conductivity structure using a dc resistivity survey. In Figure 1, we show a synthetic model that has a variety of structure. On the left, one resistive and two conductive prisms are buried beneath highly conductive surface blocks in a

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