# Constrained Sharp Boundary Inversion of Multi-Transient EM Data

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## Summary

A 1D linearized algorithm to invert Multi-Transient Electromagnetic (MTEM) data to give a subsurface resistivity model which contains sharp boundaries has been developed. Using *a priori* resistivity well log information (LLD) and seismic reflection data a blocked resistivity model is defined, with sharp boundaries separating regions of relatively constant resistivity. Within the inversion process the gradient of the solution vector at each boundary location is used to define the required perturbation of the model boundaries to reduce the RMS misfit of the inversion. The results from this inversion scheme and that of the popular Occam inversion are compared for a range of 1D and 3D synthetic MTEM datasets generated from models which contain sharp resistivity contrasts. For these synthetic datasets the character of the final model for the newly developed inversion method is consistently closer to that of the true model.

## Introduction

It is well documented that oil and gas are highly resistive when compared with other typical pore fluids, as a result accumulations of hydrocarbons can be characterised by high resistivity, a fact that is readily exploited within exploration geophysics.

One recently developed technique of generating a subsurface resistivity image from surface measurements with the aim of locating hydrocarbon accumulations is the multi-transient electromagnetic surveying method (MTEM) (Ziolkowski et al, 2007). The technique is based on measuring the transient (voltage) response observed between a pair of receiver electrodes due to a step in current, or a coded transient waveform such as a pseudo-random binary sequence (PRBS), injected at a pair of source electrodes at a given offset from the receivers (see figure 1).

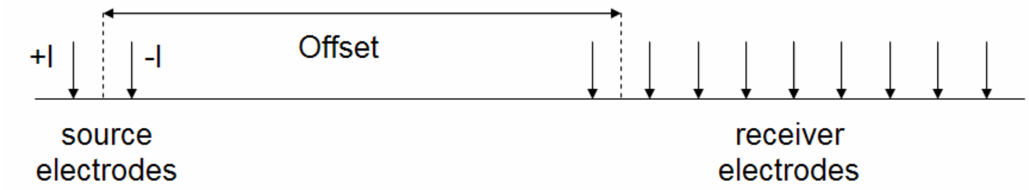


Figure 1: Schematic of MTEM acquisition geometry.

The typical form of the measured transient response, which is a function of the subsurface resistivity, can be seen in figure 2.

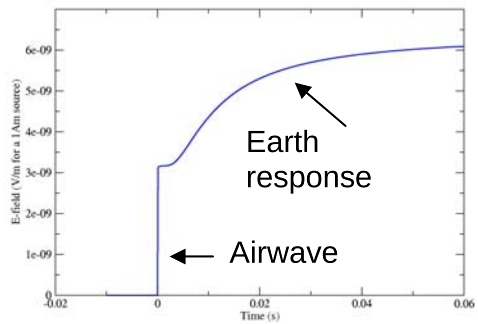


Figure 2: Typical earth step response.

One method of using this recorded transient to obtain a subsurface resistivity image is by inversion where the process aims to achieve a subsurface resistivity model whose response matches the measured data.

The type of inversion currently being used to provide 1D models for MTEM data is the popular Occam's inversion (Constable et al., 1987). This form of inversion provides the smoothest, most gently varying resistivity model possible by minimising a term defined as the model roughness within the objective function. However, in many cases the resistivity structure of the subsurface is not smoothly varying but instead contains sharp resistivity contrasts separating regions of approximately constant resistivity, as seen in typical resistivity well logs through hydrocarbon reservoirs. Therefore for cases such as these Occam inversion is unlikely to give a realistic representation of the subsurface resistivity. This paper presents a new inversion scheme to account for such sharp resistivity boundaries.

**Method**

The inversion of MTEM data is a non linear problem and therefore must be solved iteratively. The perturbation $\delta m$ to the model at each iteration can be determined through ridge regression by

$$\delta m = \left[\lambda^2 I + (WJ)^T WJ\right]^{-1} (WJ)^T WD$$

where $\lambda$ is the damping factor, $J$ is the Jacobian matrix, *D* represents the data and *W* is a weighting matrix. A systematic relationship was found between the gradient of $\delta m$ and the correct boundary position. $\delta m$ was calculated for a range of test models each with an incorrectly placed sharp resistivity contrast, given synthetic data from a model with a similar resistivity contrast and a boundary at 500 m depth (see figure 3).

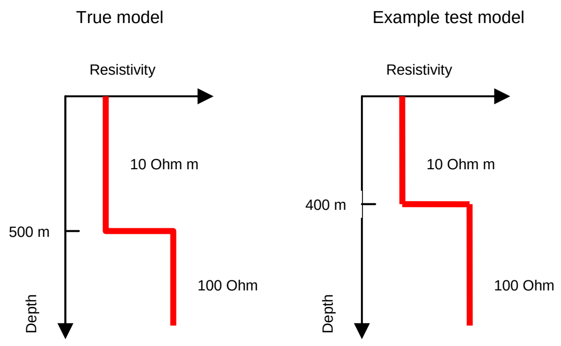


Figure 3: Synthetic model and example test model

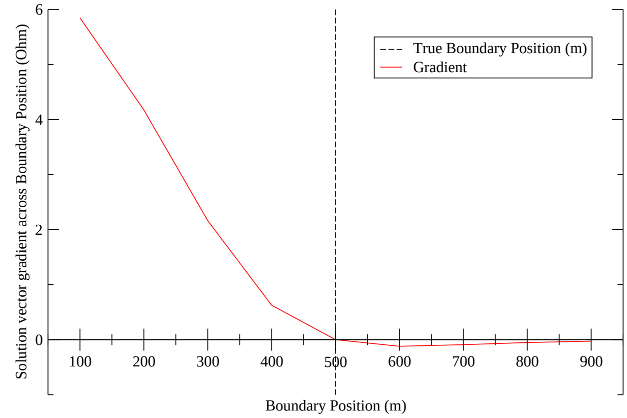


Figure 4: Gradient of $\delta m$ for different test models

Figure 4 shows that if the boundary in the test model is too deep the gradient is negative and if too shallow the gradient is positive. This relationship forms the basis upon which the new inversion scheme operates and was shown to be stable for a range of tests including 3 layer models, varying resistivities and noisy data.

## Gradient Inversion of 1D Synthetic Models

The gradient inversion scheme was applied to a range of 1D synthetic datasets derived from models which contained sharp resistivity contrasts. Two of these are shown in Figures 5 and 6. Multi trace inversion was used, incorporating synthetic data modelled at offsets of 1000 m, 2000 m and 3000 m. In these figures the green curve is the true model, the blue curve is the starting model and the red curve is the resistivity structure determined by gradient inversion. The start models for the gradient inversion in the case of real data would be defined from *a priori* information. The boundaries have been moved substantially and are close to their correct locations. Occam derived inversions are shown for comparison.

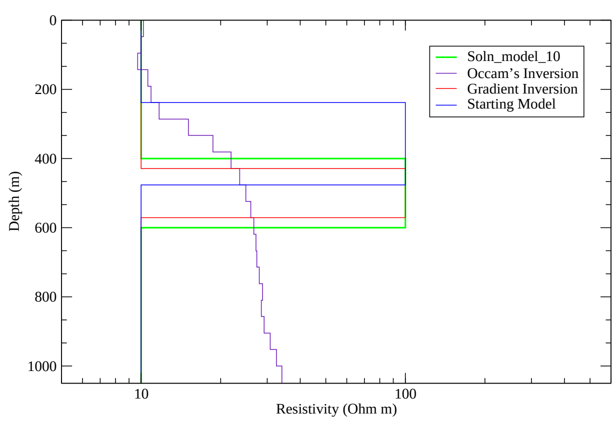


Figure 5: A 3-layer test model with a resistive layer

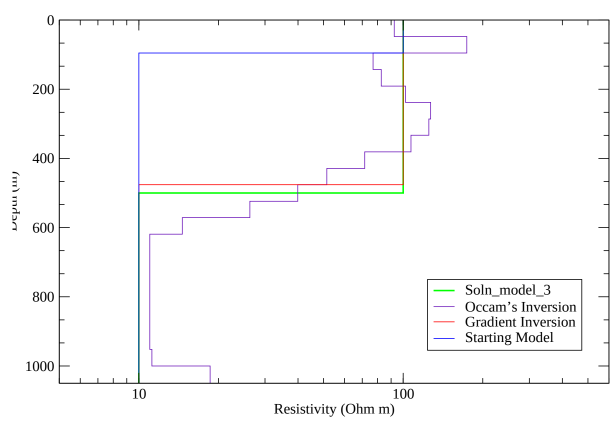


Figure 6: A 2-layer resistor/conductor model

The inversion models were parameterised into 20 layers of equal thickness to a depth of 1000m overlying a half space. Both the Occam and gradient inversion give good fits to the synthetic data. However it is clear that the gradient method model is a closer representation to the true resistivity structure than the model given by Occam's inversion.

### Gradient Inversion of 3D Synthetic Data

The gradient inversion was then applied to a synthetic dataset derived from a 3D model. The model used was designed to be representative of shallow tar sand deposits which had been a target of a previous MTEM survey and was chosen due to its sharp resistivity contrasts. Synthetic data were generated at a regular spacing along a 5500m long profile which spanned the full length of the model. Synthetic response data were generated for 92 CMP positions along the profile and modelled for offsets of 300m, 400m and 500m.

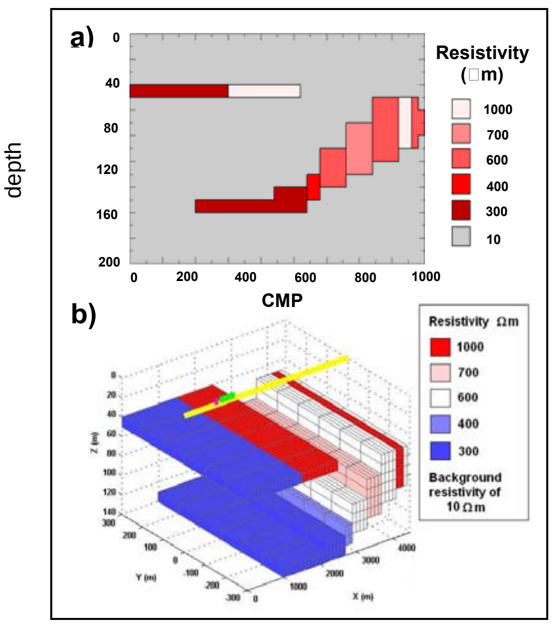


Figure 7: Cross-section and 3D view of test model

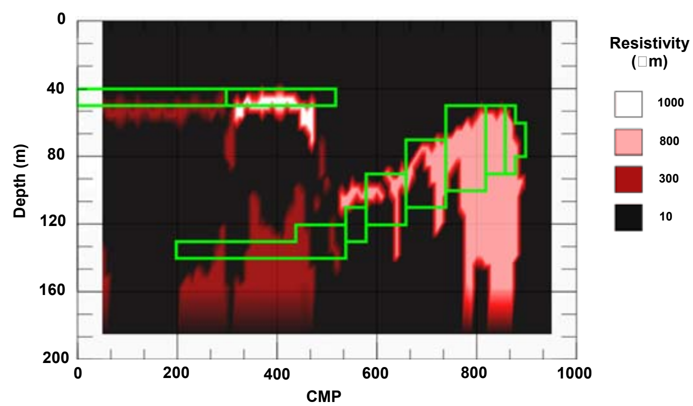


Figure 8: Gradient inversion of tar sands model.

Figure 7 shows a cross section and a 3D view of the model used to generate the synthetics. A start model for the gradient inversion was specified based on the a priori information used to generate the 3D model, namely a set of resistivity logs. The parameterisation for the inversions consisted of 32 layers of equal thickness to a depth of 160m, overlying a uniform half space. To generate the final image each CMP was inverted separately in 1D and these inversions were collated to form the 2D cross-section shown in Figure 8. The shallow resistor has been imaged well along with the upper boundary of the dipping structure. The new method successfully detects the lower resistive layer beneath the shallow resistor. Occam inversion (not shown here) fails to resolve the two resistive targets.

## Conclusions

A new inversion shceme, termed gradient inversion, exploits a relationship found in the solution vector $\delta m$ during ridge regression for models containing sharp resistivity boundaries. This inversion scheme was successfully applied to a range of synthetic datasets. The results show that for models containing sharp resistivity boundaries the gradient method provides a solution which reflects the character of the true model better than the model provided by Occam inversion. The method has also been applied to a real MTEM data set where *a priori* data from well logs and seismics were used to construct a starting model. The results will be shown in the full presentation.

#### References

Constable, S. C., Parker, R. L., and Constable, C. G. (1987) Occam's Inversion: A practical algorithm for generating smooth models from electromagnetic sounding data. *Geophysics*. 52:289-300.

Ziolkowski,A.M., Hobbs,B.A. & Wright,D.A., 2007. Multi-Transient Electromagnetic Demonstration Survey in France, Geophysics, 72, 197-209.