Constrained Sharp Boundary Inversion of Multi-Transient EM Data

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Summary

A 1D li nearized algorithm to in vert Multi-Transient Electromagnetic (MTEM) data to g ive a subsurface resistivity model which contains sharp boundaries has been developed. Using *a priori* resistivity well log information (LLD) and seismic reflection data a blocke d resistivity model is defined, with sharp boundari es separating regions of relatively constant resistivity. Within th e inversion process the gradient of the solution vector at each boundary location is used to define the required perturbation of the mode l boundaries to reduce the RMS misfit of the i nversion. The results from this in version scheme and that of the popular Occ am inversion are compared for a range of 1D and 3D synthet ic MTEM datasets generated from models which contain sharp resistivity contrasts. For these synthetic datasets the character of the fi nal model fo r the newly developed inversion method is consistently closer to that of the true model.

Introduction

It is well docum ented that oil an d gas ar e highly res istive when compared with ot her 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 generati ng a subsurface resistivi ty image from surface measurements with the aim of loc ating hydrocarbon accumulations is th e 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).
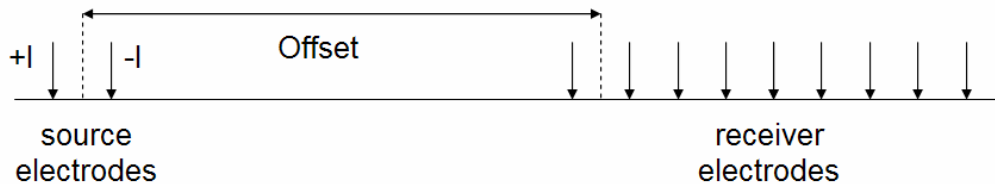
Figure 1: Schematic of MTEM acquisition geometry.

The typical form of the meas ured transient response, which is a fun ction of the subsurf ace resistivity, can be seen in figure 2.
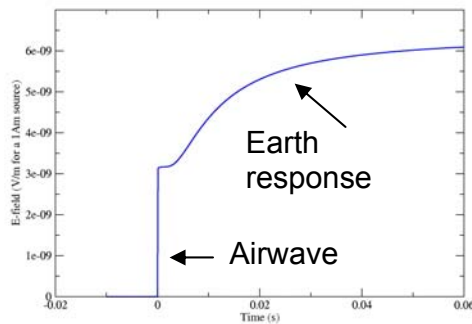

Figure 2: Typical earth step response.

One method of using this recorded transient to obtain a subsurface resistivity image is by inversion where the proc ess aims to achi eve a subs urface resistivity model whose response m atches the measured data.

The type of inver sion currently being used to pr ovide 1D models for MTE M data is the popular Occam's inversion (Constable et al., 1987). This form of inv ersion provides the smoothest, m ost gently varying resistivity model possible by minimi sing a t erm defined as the model r oughness within the objective function. Howe ver, in many cases the r esistivity structure of the s ubsurface is not smoothly varying but instead contains sharp resistivity contrasts separating regions of approximately constant resistivity, as seen i n typical resistivity well logs through hydrocarbon reservoirs. Therefore for cases such as t hese Occam inversion is unlikel y 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 so lved iteratively. The perturbation δm 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 λ is t he damping factor, J is the J acobian matrix, D represents the d ata and W is a weighting matrix. A systematic relationship was found between the gradient of δm and the correct boundary position. δm was calculated for a ran ge of test models each with an incorrectly placed sharp resistivity contrast, given synthetic data from a m odel with a similar resistivity contrast and a boundary at 500 m depth (see figure 3).
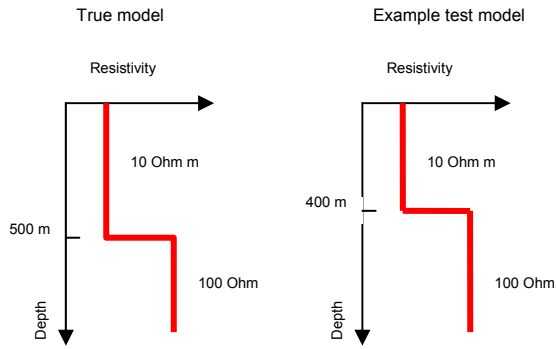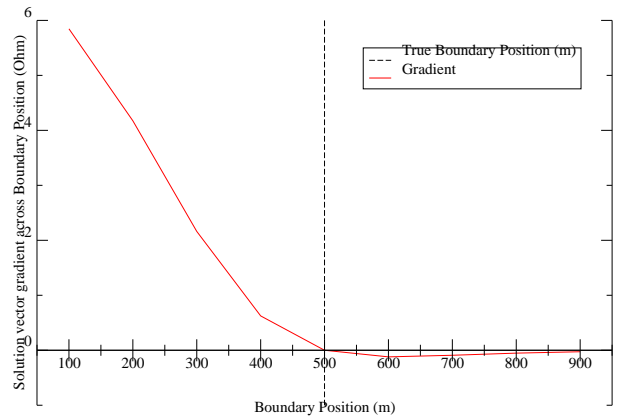
Figure 3: Synthetic model and example test model

Figure 4: Gradient of δm 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.
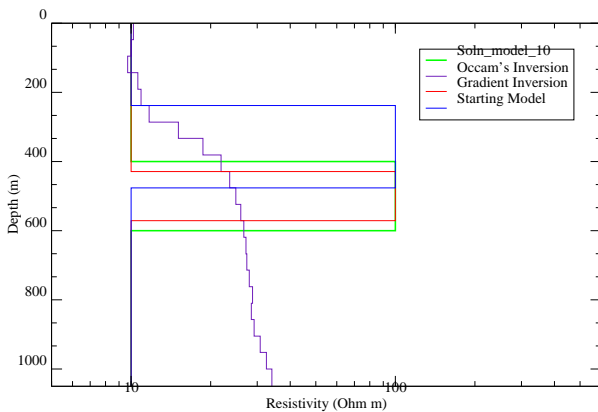

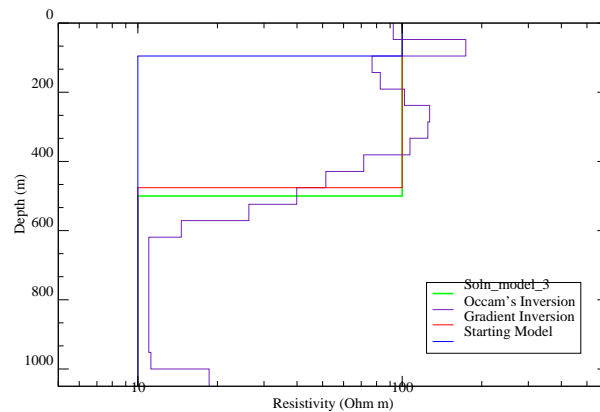Figure 5: A 3-layer test model with a resistive layer

Figure 6: A 2-layer resistor/conductor model

The inversion models wer e parameterised into 20 lay ers of equa l thickness to a depth of 10 00m overlying a half space. Both the Occam and gradient inversion give good fits to the synt hetic data. However it is clear that the gradi ent method model is a clos er 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 re presentative of shallow tar sand deposits which had b een a target of a previous MTEM survey and was chosen due to it s sharp resistivity contrasts. Synthetic dat a were generated at a regular sp acing along a 5500m long prof ile which spanned the full lengt h of the model. Synthet ic response data were generated for 92 C MP positions along the profil e and modelled for offsets of 300m, 400m and 500m.
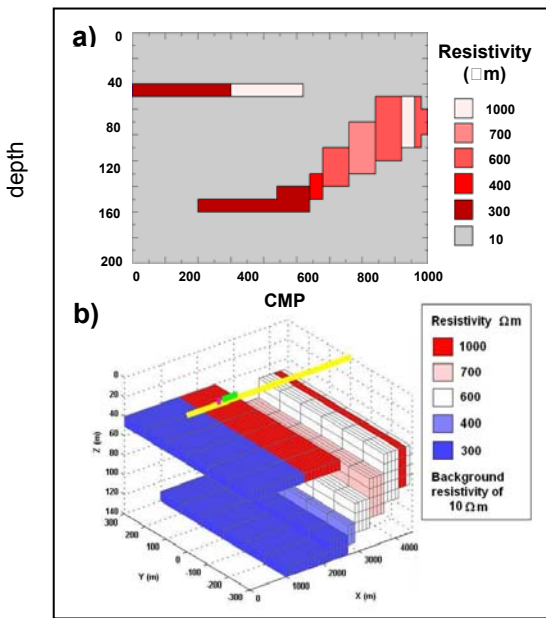

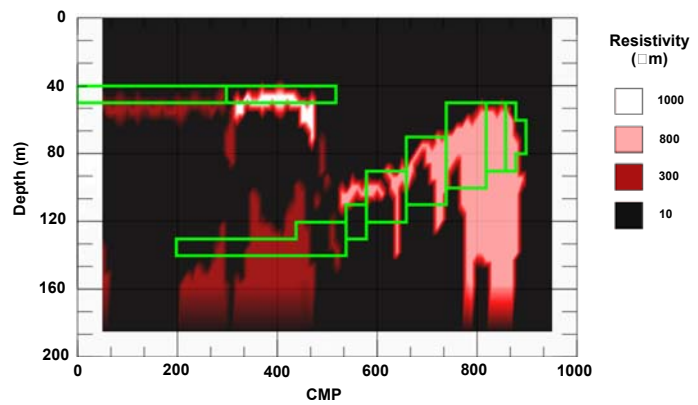Figure 7: Cross-section and 3D view of test model

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 gr adient 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, ov erlying a unif orm 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 r esistor has be en imaged well along wi th the upper boundary of the dipping str ucture. The new met hod successfully detects the lower resist ive layer beneath the shallow r esistor. Occam inversion (not s hown here) fails to reso lve the tw o resistive targets.

Conclusions

A new inversion shceme, te rmed gradient inversion, exploits a relati onship found in the solution vector δm during ridge regr ession for models cont aining sharp resist ivity boundaries. This inversion scheme was successfully applied to a range of synthe tic datasets. The results show that for models containing sharp resistivity boundaries the gradient m ethod provides a solut ion which reflects the charact er of the tr ue model better th an the model provided by Occam inversion. The method has also been appl ied 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) O ccam's Inversion: A pr actical algorithm for gen erating smooth models from electromagnetic sounding data. *Geophysics*. 52:289-300.

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