1D-Time Domain Inversion Incorporating Various Data Strategies with a Trust-Region Method

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Summary

For many years since the early 1980's, in-loop time domain inversions were not only performed but recommended by manufacturers of such equipment including the use of smooth over-parametrized models. For various reasons, we have opposed this simplistic approach and have sought more precise techniques to provide higher resolution models with appropriate physical constraints. In previous research, we have studied the importance of correct system representation and how to provide more precise under-parametrized and geologically constrained models. In this paper, we have developed a constrained trust-region method to jointly invert the data of multiple stations and multiple components so as to explore the importance of utilizing multiple data elements to provide accurate and reliable results. This method has a fast convergence rate and can incorporate known geological information.

Introduction

Time-Domain Electromagnetic sounding techniques are successfully applied to various areas of geoexploration. A number of authors have made efforts to generate enhanced resolutions of inverted models by utilizing various components of data. In [1] the merits of joint inversion of surface and borehole data were studied. In [2] a 1-D laterally constrained inversion utilizing information on the neighboring 1D-models was implemented to yield an enhanced resolution of the subsurface. In [3] an attempt was made to generate a 3D-model utilizing a 1D-inversion. We applied inversion on in-loop and out-of-loop data individually and concluded that out-of-loop data may resolve deeper structures better than in-loop data [4]. In [5] it was demonstrated that a 1D multi-station inversion can assist in accurate 3D modeling of structural anomalies. In this paper, we have developed a constrained trust-region method to jointly invert the data of multiple stations and multiple components.

Trust-Region Method

Our trust region method solves a non-linear least-squares minimization problem with simple-bound constraints. During the inversion process, we construct a quadratic approximation to the objective function utilizing the Taylor series expansion. We utilized a projected gradient method to determine an initial point with sufficient reduction of the quadratic model. The projected gradient method is more efficient as several bound constraints can be added all at once. As the second stage of the step computation, a further reduction of the quadratic model is sought to enhance the convergence of the inversion with the additional restriction that the parameters on their bounds are kept fixed throughout the second process.

Results

The trust-region inversion technique was applied to a synthetic ground time domain dataset. For the synthetic survey, a 400 x 400 m loop centered at (0, 0) was used. Receiver locations were every 100 m on a north-south line from 0N to 800N (except at 200N where the north side of the loop is located). The base frequency of the system was 30 Hz, and there were 20 off-time channels. Synthetic data for this survey was created for the following 1D model: a 500 Ωm half-space with a 50 m thick, 50 Ωm conductor at 400 m depth. The starting model was a 500 Ωm half-space with a 50 Ωm, 50 m thick conductor at 160 m depth. That is, the position of the conductor has been shifted up 240m from the true model. With the conductor in the starting model at 160 m depth, a single-station inversion finds a good result only at some locations. The initial inversion (Figure 1) was a single-station inversion on the vertical component Hz with the starting model outlined above. A good model was obtained at only two data points: 300N and 600N. The inversion results at these two points were close to the true model: the resistivities of the first and third layers were close to 500 Ωm, and the conductance of the second layer was close to 1 S, as in the model. The data is not very sensitive to the conductivity of this layer, but is sensitive to the conductance. At five of the other stations (0N, 100N, 500N, 700N, and 800N), the inversion results are similar to each other, but the models do not fit the data as well. In these models, the resistivity of the top layer is close to 500 Ωm, but the second layer is a strong resistor at 200 m, followed by a somewhat conductive layer of about 200 Ωm. These models fit the data well at early times, but do not match its curvature at mid-late times (Figure 2).

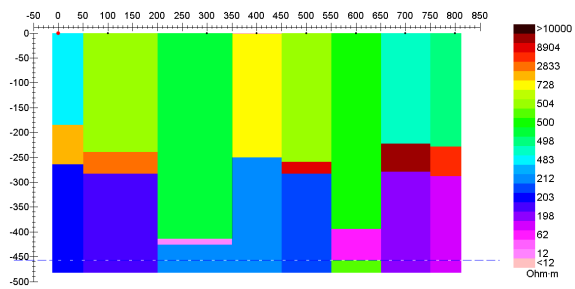

Fig.1 Stacked 1D inversions results for the single station inversion of Hz.

The use of the multi-station inversion technique significantly improved inversion results for Hz. In a multi-station inversion using all eight stations, excellent results were obtained (Figure 2). The model fits the data well and is close to the true model. The misfit of the model to the data was below 1% in only five iterations. Another multi-station inversion, utilizing only stations 0N and 800N had good results as well. Both of these locations had poor results in the single-station inversion, but when used together in the multi-station inversion, a much better model was found. This result is due to the ambiguity in the model at a single station whereas the multi-station data seems to have only one reasonable model.

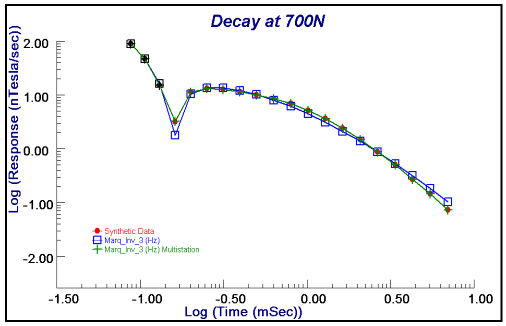

Fig.2 Decay at 700N. Red is the synthetic data. Blue is the result of the single-station inversion on Hz at 700N. Green is the result of the multi-station inversion on all eight stations.

Conclusion

It is possible to apply multiple time domain data elements to a trust-region inversion for a single multi-layer model. Such multiple data elements can be data from multiple stations and/or data from different data components. The extension to multiple data components has a variety of benefits including the ability to enhance the signal to noise characteristics in the inversion process and large reductions in the number of suitable models.

References

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