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UBC-GEOPHYSICAL INVERSION FACILITY: CAPABILITIES FOR ELECTROMAGNETIC MODELLING AND INVERSION OF LSBB DATA

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ABSTRACT

This talk presents the capabilities of the UBC-Geophysical Inversion facility (UBC-GIF) for working with numerical modeling and inversion problems associated with various electromagnetic (EM) research projects ongoing at LSBB. Of particular interest are frequency and time domain EM problems involving controlled sources. In our work Maxwell's equations are discretized with finite volume methods and solved iteratively or, more recently, by using direct solvers. The physical properties of most interest are the electrical conductivity and magnetic permeability, and data are acquired in the quasi-static regime. For zero frequency, Maxwell's equations reduce to the DC resistivity equations and these play an important role in mineral exploration and in problems such as finding water near mine tunnels. Our 3D frequency and time domain EM inversions have been successful in mineral exploration problems involving airborne and surface transmitters and airborne, surface and downhole receivers. These codes and methodologies for inversion should also be successful in research problems connected with the LSBB where transmitters and receivers are in tunnels or boreholes.

INTRODUCTION

The Geophysical Inversion Facility was founded in 1987 as a unit within the department of Geophysics and Astronomy and its goal was to interact with industry and enhance their capabilities to use geophysical data for mineral exploration. The unit has been funded consistently by a consortium of mining companies. Our over-riding research goal has been to develop practical methodologies and computer software to recover 3D distributions of physical properties from the geophysical data. The first data sets to be inverted with were potential fields, gravity and magnetic data. This was followed by 3D inversion of DC resistivity and IP (Induced Polarization) data. During the last decade we have focused upon 3D inversion of frequency and time domain data. Programmers at GIF have produced robust, commercially viable software with documentation and example inversions. These have been provided to the sponsors. The inversion codes, particularly 3D potential fields and DC/IP are currently used on a daily basis by the industry. In our current research we are continuing to make our codes more efficient numerically, develop workflows for inverting data, and further develop methodologies and software to integrate various types of geophysical and geological information into our inversions.

Although the GIF mandate was to work on mineral exploration problems, that has long ago been revised to include the application of inversion to many other types of problems including UXO (Unexploded Ordnance) discrimination, geotechnical, and environmental problems.

METHODOLGY AND SOME RESULTS

In a geophysical experiment we are provided with data d_j^{obs}, ($j=1,\ldots, n$), an estimate of the uncertainty of each datum n_j and an ability to carry out forward modeling $F_j(m) = d_j$. $F_j(m)$ incorporates details of the survey design and relevant physical equations, m is a generic symbol for a physical property distribution. The goal of the inverse problem is to extract information about m from a finite number of inaccurate data. We formulate the inverse problem as a standard optimization where we find a specific solution m that minimizes $\phi = \phi_d + \beta\phi_m$ where $\phi_d = \left\| W_d (d - d^{obs}) \right\|^2$ is the squared misfit between the observed and predicted data. W_d is a diagonal matrix W=diag(1/ε) where ε is the estimated standard deviation of the *jth* datum. The quantity $\phi_m = \left\| W(m - m_{ref}) \right\|^2$ is the model objective function. m_{ref} is a reference model and the matrix W is a regularization matrix that produces a model that is close to m_{ref} and also has minimum structure in the three spatial directions. This allows the user to incorporate other information to get a model that is compatible with prior knowledge or expected outcomes. By minimizing this quantity we obtain a solution with minimum structure. β is a positive constant and its value regulates the tradeoff between amount of structure and misfit of the data.

A numerical solution is obtained by differentiating the above objective function and solving the Gauss-Newton system of equations

$$(J^T W_d^T W_d J + \beta W^T W)s = -g(m)$$

where *s* is a sought perturbation and *g(m)* is the gradient. The perturbation is added to the previous model and the procedure iterated until convergence.

Formulating the inverse problem in this manner is now commonly done and a plethora of books on inverse theory and optimization exist. For more details about how the GIF codes are handled and examples for mineral exploration problems, the reader is referred to [1], [2], [4]. Further, there is a free downloadable package (IAG Inversion for Applied Geophysics) that can be obtained from UBC via Flintbox. [5]

As a specific example we show some previous work in an underground mine where the goal was to find a source of water that was infiltrating the mine. The Mosaic potash mine in Esterhazy Saskatchewan was infiltrated by water (Figure 1).

Fig. 1 Water infiltrating an underground potash mine in Saskatchewan.

The major leak was eventually stopped and the area grouted but there was concern that further water sources would be encountered while mining. As a result a 3D DC survey was planned. Forward modeling and inversion of synthetic data was carried out to help design the survey. Hardware was provided by Golder Assoc and they adapted it to provide extended lengths for electrode placements in the full extent of the available drifts, raises, and subdrifts.

Electrode sequences were designed using standard electrode arrangements (Wenner-Schlumberger, Dipole-Dipole) as well as random dipole arrangements to image the full extent of an area. The UBC inverse modeling software provided the flexibility to utilize the random arrangements.

In the mine survey, the borehole electrodes were placed at the top of three initial vertical boreholes. The electrodes were also placed at halfway locations in the boreholes during data collection to improve resolution of the imaging. After the data were processed, additional boreholes were drilled based on the modeling of undersampled areas, particularly the southwest half of the area. Subsequent data sets were collected from the additional boreholes.

The final 3D model is illustrated in Figure 2. Two regions of high conductivity, interpreted as saline water, are observed. This model has been developed from a data set of over 25,000 readings. The data were carefully analyzed to address noise issues, infrastructure interference, and range. Interference has been isolated to electrodes in vicinity of power transformers, ventilation fans, and other electrical equipment. Follow-up drilling using the inversion models has revealed voids and wet areas in good agreement with the models.

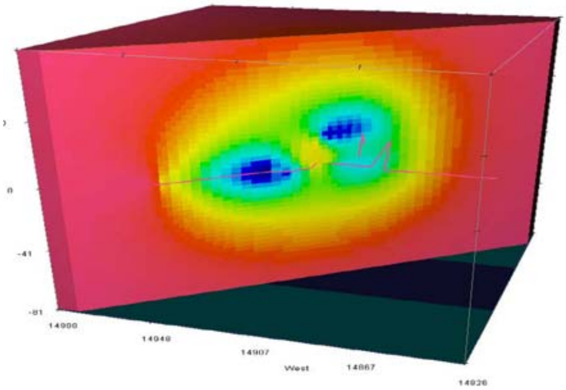

Fig. 2 Cross section through the 3D conductivity volume obtained by inverting DC resistivity data. The blue regions (dark in grey scale) represent locations of water.

SUMMARY

The work presented here offers a limited insight into the inversion capabilities and range of problems dealt with at GIF. Although DC resistivity is show-cased as a major survey type for in-mine problems, time and frequency EM surveys also hold much promise.

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