Inversion of moving-loop TDEM data using trust-regions: a case study from the Athabasca Basin

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ABSTRACT

Geophysical exploration of Uranium deposits in Athabasca Basin (Canada) relies on targeting graphitic conductors, which correspond to conductive, thin, steeply-dipping plate-like structures (e.g. Nimeck and Koch, 2008). These objects present a very high resistivity contrast with their host rock. Precise modeling of graphitic conductors is key to define drilling targets, as they are closely related to mineralization. Time-Domain Electromagnetic (TDEM) methods have good sensitivity to these structures and are the methods of choice in the Athabasca.

Inversion of TDEM data is an ill-posed problem requiring regularization to converge to a reliable solution. This could be a smooth solution or close to a reference model. Regularization is weighted in the objective function. Finding the optimal weight implies performing many inversions with different values. Avoiding a search for the optimal weight would save a lot of time.

Trust-region is a numerical optimization method we are proposing to solve the inverse problem (e.g. Conn et al., 2000; Nocedal and Wright, 2006). We iteratively search for local minimizers of quadratic models of the objective function, here the L2-norm of the difference between predicted $\boldsymbol{d_{pred}}$ and observed $\boldsymbol{d_{obs}}$ data, inside a region in which we trust the model to be a good approximation. The radius Δ of the trust region is going to control the size of the model perturbation $\boldsymbol{x}$ but also influences its direction. At each iteration we solve a trust-region subproblem which aims to find a solution to a non-linear least-squares problem with a constraint on the size of the solution.

$$(J^T J + \lambda I)\,\boldsymbol{x} = -J^T\left(\boldsymbol{d_{pred}} - \boldsymbol{d_{obs}}\right)$$

$$\|\boldsymbol{x}(\lambda)\|_2 \;\leq\; \Delta$$

To satisfy the constraint on the size of the model perturbation, a multiplier of the absolute value of the smallest eigenvalue λ is added to the diagonal of the approximate Hessian $J^T J$. This added value acts as a damping factor and then the size of the trust-region defines the weight given to the regularization. Once a perturbation is calculated, a response is computed. The ratio of the reduction in the objective function and the reduction predicted by the model allows us to evaluate if the perturbation is acceptable and if the radius of the trust-region must be modified. Thus, the regularization is automatically updated depending on the success of the previous steps.

We applied a trust-region algorithm for 2D inversions of Moving-Loop TDEM survey lines acquired by Orano Canada Inc. in the Athabasca Basin. We used the vertical component of the magnetic flux over 15 channels for 26 stations separated by 200m. Source-receiver offset is 800m.

Forward Modeling was done with SimPEG (Cockett et al. 2015) on a 3D TensorMesh of 96000 cells. The 2D inversion mesh contains 1600 parameters and extends from -8000m to 8000m laterally and 0 to 4000m depth.

Starting from a homogeneous 1000Ω.m half-space, after 30 iterations, predicted and observed data are in good agreement. The obtained models are consistent with the existing knowledge of the area of interest.

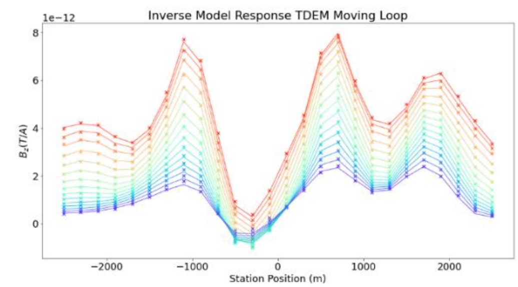

Figure 1: Vertical component of the magnetic flux showing observed (cross) and predicted (lines) data after 30 iterations.

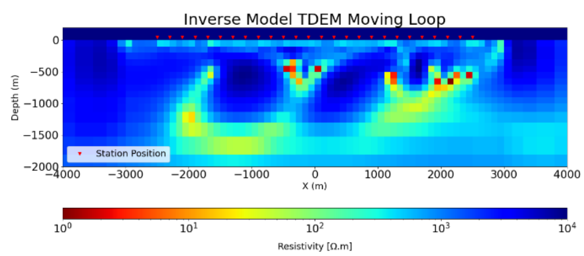

Figure 2: Inverse Model obtained after 30 iterations. Resistivity values and structures are consistent with drilling results.

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