Applying a multi-transmitter hybrid Conjugate Gradient-Occam algorithm to the inversion of 3D mCSEM data

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SUMMARY

We present the results of applying a hybrid conjugate gradient-Occam inversion algorithm to 3D marine CSEM data. The Occam scheme is a very effective way of dealing with the particular problem of choosing a value for the regularization parameter in an inverse problem. However, in the traditional implementation, the full Jacobian matrix is required—something which is not feasible for realistic 3D problems. Thus, iterative search algorithms which do not require the full Jacobian, such as NLCG, LBFGS, or iterative solution of the Gauss-Newton (GN) normal equations, are most commonly used for solving 3D EM inverse problems. Hybrid algorithms offer another option. In the basic hybrid scheme, the dataspace GN normal equations are solved iteratively (without computing the full Jacobian), but results of the forward and adjoint calculations required for each iterative step are saved. These are then used to construct a low dimensional approximation to the full Jacobian, and hence the GN equations. By solving the low-dimension approximate GN equations multiple times with different regularization parameters, an approximate Occam scheme can be efficiently realized. In addition to allowing use of GN methods such as Occam, generation of an approximate Jacobian through this hybrid approach will allow more complete and efficient exploration of trade-offs between fitting different data types (e.g., MT as well as CSEM), and provides an approximation to the linearized resolution operator.

For most EM inverse problems there are in fact multiple transmitters, characterized by source frequency and/or location. Gradient based optimization schemes (such as NLCG, as used in ModEM) require solving adjoint problems for every transmitter. Each of these is essentially the gradient (in the model space) of the data misfit penalty, restricted to data from that transmitter. The standard schemes merge these into a single gradient vector. With the multi-transmitter hybrid scheme we save all of this information about penalty functional gradients, and then uses this to form an improved approximation to the full Jacobian. We can anticipate that saving all of this information will be especially useful for mCSEM, and joint mCSEM/MT inversions – primarily because the transmitters (different dipole locations for mCSEM; plane wave sources for MT) are all quite different, so the corresponding gradient components will be more nearly independent. We are currently testing this idea using a mixture of Matlab and Fortran—the inversion algorithms being tested are coded in Matlab, and forward and sensitivity calculations are implemented through calls to ModEM. Communication between the two codes is through disk I/O. Although there is some loss of efficiency with such an approach, development and testing new algorithmic concepts is much faster in Matlab (especially since we already have a substantial Matlab code base). In our presentation we will present details on the new algorithms, and compare performance against other algorithms (e.g., NLCG) in terms of memory, number of iterations required for convergence, and total computing time.

Keywords: mCSEM inversion, Occam, hybrid, Conjugate Gradient