Geophysical Research Abstracts
Vol. 17, EGU2015-4402, 2015
EGU General Assembly 2015

Parallelized Three-Dimensional Resistivity Inversion Using Finite Elements And Adjoint State Methods

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The resistivity method is one of the oldest geophysical exploration methods, which employs one pair of electrodes to inject current into the ground and one or more pairs of electrodes to measure the electrical potential difference. The potential difference is a non-linear function of the subsurface resistivity distribution described by an elliptic partial differential equation (PDE) of the Poisson type. Inversion of measured potentials solves for the subsurface resistivity represented by PDE coefficients.

With increasing advances in multichannel resistivity acquisition systems (systems with more than 60 channels and full waveform recording are now emerging), inversion software require efficient storage and solver algorithms. We developed the finite element solver Escript, which provides a user-friendly programming environment in Python to solve large-scale PDE-based problems (see https://launchpad.net/escript-finley). Using finite elements, highly irregular shaped geology and topography can readily be taken into account. For the 3D resistivity problem, we have implemented the secondary potential approach, where the PDE is decomposed into a primary potential caused by the source current and the secondary potential caused by changes in subsurface resistivity. The primary potential is calculated analytically, and the boundary value problem for the secondary potential is solved using nodal finite elements. This approach removes the singularity caused by the source currents and provides more accurate 3D resistivity models.

To solve the inversion problem we apply a 'first optimize then discretize' approach using the quasi-Newton scheme in form of the limited-memory Broyden-Fletcher-Goldfarb-Shanno (L-BFGS) method (see Gross & Kemp 2013). The evaluation of the cost function requires the solution of the secondary potential PDE for each source current and the solution of the corresponding adjoint-state PDE for the cost function gradients with respect to the subsurface resistivity. The Hessian of the regularization term is used as preconditioner which requires an additional PDE solution in each iteration step. As it turns out, the relevant PDEs are naturally formulated in the finite element framework. Using the domain decomposition method provided in Escript, the inversion scheme has been parallelized for distributed memory computers with multi-core shared memory nodes.

We show numerical examples from simple layered models to complex 3D models and compare with the results from other methods. The inversion scheme is furthermore tested on a field data example to characterise localised freshwater discharge in a coastal environment..

References:
L. Gross and C. Kemp (2013) Large Scale Joint Inversion of Geophysical Data using the Finite Element Method in escript. ASEG Extended Abstracts 2013, http://dx.doi.org/10.1071/ASEG2013ab306