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Inversion of Realistic Models Using the Gauss-Newton Algorithm

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Given the challenges posed by the current exploratory frontiers of oil fields and the growing demand for computational simulations based on complex and geologically representative geoelectrical models, this study aims to evaluate the effectiveness of the Gauss-Newton inversion algorithm under such conditions. Second-order optimization methods, such as Gauss-Newton, stand out for their ability to incorporate information regarding model uncertainties, especially in deeper regions and in media characterized by high structural and resistivity variability, without invert the Hessian matrix. To compute the action of the Hessian operator on a vector in the model parameter space, the adjoint-state method was employed. This formulation, based on derivatives, is conceptually straightforward, computationally efficient, and has a cost proportional only to the number of observations, being independent of the number of model parameters. Complementing this approach, the electromagnetic fields and their adjoints were modeled in the time domain as fictitious wave-like fields and solved using finite-difference methods. This enabled the simultaneous simulation of multiple frequencies and accelerated the solution of the forward problem through parallel computing using OpenMP and GPU resources. The method's effectiveness was assessed by comparing the models estimated using the steepest descent and Gauss-Newton algorithms, alongside an analysis of different regularization and stabilization strategies for the inverse problem. Spatial smoothness constraints were imposed on the distribution of physical properties, and gradient preconditioning techniques were applied to the gradient of the objective function, including an illumination compensator and an adaptive gradient strategy. The latter begins with uniform updates across all parameters and gradually shifts toward weighted updates based on the local sensitivity of the objective function. The results indicate that, although the Gauss-Newton method was not able to accurately delineate the geometry of resistive bodies or precisely estimate the absolute values of physical properties, it demonstrated robustness in identifying the main resistivity contrasts and in correctly locating geophysical anomalies. This was achieved even in geologically complex settings and with a coarse inversion mesh, highlighting the method’s suitability for realistic subsurface modeling scenarios.