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Geoelectric data modeling using Mimetic Finite Difference Method

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Nondestructive imaging and monitoring of the earth's subsurface using the geoelectric method require reliable and versatile numerical techniques for solving differential equation that govern the method's physic. The discrete operator should encompass fundamental properties of the original continuum model and differential operator for a robust numerical algorithm. In geoelectric modeling, critical model properties are anisotropy, irregular geometry, and discontinuous physical properties, whereas vital continuum operator properties are symmetry, the positivity of solutions, duality, and self-adjointness of differential operators and exact mathematical identities of the vector and tensor calculus. In this study, to simulate the response, we use the Mimetic Finite Difference Method (MFDM), where the discrete operator is constructed based on the support operator [1]. The MFDM operator mimics the properties mentioned above for structured and unstructured grids [2]. It is achieved by enforcing the integral identities of the continuum divergence and gradient operator to satisfy the integral identities by discrete analogs.

The developed algorithm's accuracy is benchmarked using the analytical responses of dyke models of various conductivity contrasts for pole-pole configuration. After verifying the accuracy of the scheme, further tests are conducted to check the robustness of the algorithm involving the non-orthogonality of the grids, which is essential for simulating response for rugged topography. The surface potential is simulated using structured grids for a three-layer model. Subsequently, the orthogonal girds are distorted using pseudo-random numbers, which follow a uniform distribution. To quantify the distortion, we calculated the angles at all grid nodes. The node angles emulate a Gaussian distribution. We characterize those grids as highly distorted, for which the angle at the grid node is outside 20 to 160 degrees interval. The numerical tests are conducted by varying degrees of grid distortion, such that the highly distorted cells are from 1% to 10% of the total cells. The maximum error in surface potential stays below 1.5% in all cases. Hence, the algorithm is very stable with grid distortion and consequently can model the response of a very complex model. Thus, the developed algorithm can be used to analyze geoelectrical data of complex geological scenarios such as rugged topography and anisotropic subsurface.

[1] Winters, Andrew R., and Mikhail J. Shashkov. *Support Operators Method for the Diffusion Equation in Multiple Materials*. No. LA-UR-12-24117. Los Alamos National Lab.(LANL), Los Alamos, NM (United States), 2012.

[2] Lipnikov, Konstantin, Gianmarco Manzini, and Mikhail Shashkov. "Mimetic finite difference method." *Journal of Computational Physics* 257 (2014): 1163-1227.