

Massive parallel 3D simulation of time-domain electromagnetic data using survey decomposition

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SUMMARY

Accurate and rapid 3D time-domain electromagnetic (TEM) data simulation is crucial for high-resolution 3D subsurface imaging and modern geological exploration. However, this task has long been considered computationally intensive and time-consuming because it requires multiple numerical solutions of the 3D Maxwell's equations. The survey decomposition (SD) theory treats any electromagnetic survey dataset as a collection or superposition of numerous independent measurements made by electric or magnetic dipole devices. Our approach significantly improves computational efficiency through three measures.

Firstly, in time, SD abandons the sequential time stepping from early to late time channels and instead determines a characteristic time step for each time channel based on its temporal scale. This constant characteristic time step is then used for local discretization in time, stepping from the starting point to the desired time channel. Consequently, multiple time channels at the same receiver can be computed independently in parallel. Secondly, in space, SD represents large-scale extended sources as linear combinations of many dipoles. Using a rotated local grid, it efficiently computes the TEM response at individual receivers excited by a single dipole source. This local grid is optimized only for specific source-receiver pairs at a particular time channel, resulting in many independent and easily solvable S-R-T (Source-Receiver-Time) subproblems. The impact of sources on electromagnetic field responses varies across different time channels. Early times exhibit shallow diffusion depths, larger response amplitudes, and higher spatial resolutions, necessitating a finer subdivision of sources for computing early-time electromagnetic responses. In contrast, late times have deeper diffusion depths and lower resolutions, allowing for sparser decomposition of sources to reduce the number of dipole problems. The study uses uniform half-space calibration to investigate the relationship between the decomposition of extended sources, the measured time channel, and the geoelectric model. Thirdly, we have developed a distributed parallel computing program to harness the increasing availability of parallel computing resources in recent years. This program improves the parallel computing efficiency of many local TEM subproblems. It comprises scanning mode and computing mode components: the scanning mode monitors global "start" and "end" commands, while the computing mode handles subproblems without communicating between computing nodes. Moreover, during execution, the number of subproblems solved by each node dynamically adjusts based on the computational capabilities of individual threads. This new parallel computing scheme effectively addresses common issues in traditional large-scale parallel computing, such as stability, load balancing, and scalability, and it is particularly suitable for many independent local electromagnetic subproblems in the SD framework.

This study demonstrates the application of a new decentralized SD parallel algorithm in three-dimensional models of varying complexity, considering large loop sources or grounded wire sources. Comparative analysis with other numerical algorithms shows that this algorithm meets accuracy requirements while enhancing computational efficiency. Using the realistic geoelectric model of Tli Kwi Cho in Canada, the efficiency of the SD algorithm was investigated on the "Taiyi" supercomputing cluster of the Southern University of Science and Technology. The tests revealed that the computation time decreases approximately linearly with the number of cores; no degradation in acceleration performance was observed when the maximum allowable number of cores (32000) is reached. Moreover, our new fast modeling approach results are within a 6% discrepancy compared to the traditional method using a single global mesh. The linear speedup observed in numerical experiments demonstrates the superior scalability of our approach, indicating that modern algorithms and computing devices can accurately solve 3D TEM modeling of arbitrary scales within seconds to minutes.

Keywords: Time-domain electromagnetic, Survey decomposition, Parallel computing, Numerical modeling
