Multi-GPU accelerated parallel modelling and inversion for geophysical electromagnetic problems

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SUMMARY

The Curl-Curl equations is the fundament for time-harmonic electromagnetic (EM) problems in geophysics. The forward and adjoint calculations with the discretized Curl-Curl equations are computationally intensive and crucial to frequency domain geophysical EM inversions like Magnetotellurics and Controlled Source EM. However, most published algorithms are still CPU-based and cannot benefit from the rapid development of modern large-scale multi-GPU parallel architectures driven by the AI boom. Based on the previously proposed divergence-free modelling algorithm for CPUs, we develop a hybrid parallel paradigm to exploit the high-throughput of interconnected heterogenous parallel systems equipped with multiple GPUs. The large sparse linear system derived from the staggered-grid finite-difference approximation of Curl-Curl problem is decomposed into sub-domains to mitigate the limitation of the memory size of a single GPU card. The system is then solved efficiently with a mixed-precision Krylov subspace GPU algorithm in parallel, utilizing the fast device-to-device interconnection of NVIDIA NVlink bridges. To show how the large-scale inversion problems can be substantially accelerated, we implement the new algorithm in the ModEM framework and test the algorithm with real-world 3D problems. We examine the efficiency of our new algorithm in forward and adjoint calculations with an MT problem with ~4 million model cells and 723 stations. The results from a GPU node equipped with 6 consumer-grade NVIDIA RTX 3090 cards demonstrate a promising ~2.5x speed-up, when compared with conventional CPU-based algorithm on a server cluster with 12 nodes. This development may significantly reduce the computation time and carbon footage for large-scale frequency domain EM inversion problems and brings the possibility of near real-time EM imaging, for engineering and environmental applications.

Keywords: multi-GPU, Curl-Curl equations, inversion, domain-decomposition, mixed-precision