WaveQLab3D: A Numerical Software for Waves and Dynamic Earthquake Rupture Simulations

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Abstract

Dynamic earthquake rupture simulations are critical for understanding fault mechanics and improving seismic hazard assessments. In this work, we present recent developments in WaveQLab3D, a high-performance numerical software suite designed for large-scale simulations of seismic wave propagation and spontaneous rupture dynamics. We apply the code to the Southern California Earthquake Center (SCEC) benchmark problems TPV36 and TPV37, which test rupture propagation to the surface and rupture arrest at depth on a shallow-dipping thrust fault. Within the summation-by-parts (SBP) finite-difference framework, we implement and compare traditional central operators, upwind dual-pairing operators, and dispersion-relation-preserving operators.

Our results highlight trade-offs between accuracy, stability, and efficiency across these schemes, with implications for modeling rupture kinematics and surface deformation. To enhance reproducibility and cross-code validation, we have also developed interactive dashboards in R and Python for systematic visualization and comparison of benchmark results. Together, these advances establish **WaveQLab3D** as a flexible platform for numerical experimentation, benchmarking, and visualization in computational seismology.

Keywords

WaveQLab3D; dynamic rupture; seismic wave propagation; SBP finite differences; computational seismology; SCEC benchmarks