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Petascale computation of multi-physics seismic simulations

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Capturing the observed complexity of earthquake sources in concurrence with seismic wave propagation simulations is an inherently multi-scale, multi-physics problem. In this presentation, we present simulations of earthquake scenarios resolving high-detail dynamic rupture evolution and high frequency ground motion. The simulations combine a multitude of representations of model complexity; such as non-linear fault friction, thermal and fluid effects, heterogeneous fault stress and fault strength initial conditions, fault curvature and roughness, on- and off-fault non-elastic failure to capture dynamic rupture behavior at the source; and seismic wave attenuation, 3D subsurface structure and bathymetry impacting seismic wave propagation.

Performing such scenarios at the necessary spatio-temporal resolution requires highly optimized and massively parallel simulation tools which can efficiently exploit HPC facilities. Our up to multi-PetaFLOP simulations are performed with SeisSol (www.seissol.org), an open-source software package based on an ADER-Discontinuous Galerkin (DG) scheme solving the seismic wave equations in velocity-stress formulation in elastic, viscoelastic, and viscoplastic media with high-order accuracy in time and space. Our flux-based implementation of frictional failure remains free of spurious oscillations. Tetrahedral unstructured meshes allow for complicated model geometry. SeisSol has been optimized on all software levels, including: assembler-level DG kernels which obtain 50% peak performance on some of the largest supercomputers worldwide; an overlapping MPI-OpenMP parallelization shadowing the multiphysics computations; usage of local time stepping; parallel input and output schemes and direct interfaces to community standard data formats. All these factors enable aim to minimise the time-to-solution.

The results presented highlight the fact that modern numerical methods and hardware-aware optimization for modern supercomputers are essential to further our understanding of earthquake source physics and complement both physic-based ground motion research and empirical approaches in seismic hazard analysis.

Lastly, we will conclude with an outlook on future exascale ADER-DG solvers for seismological applications.