Report of Transnational Access Project CapCosSC-HPC

Project ID: C2_TA2-531-1-2

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Project title: Capturing co-seismic stress changes with High Performance Computing enabled dynamic rupture models of megathrust earthquakes

Project acronym: CapCosSC-HPC

Hosting installation: TA2-531-1 SeisSol/ExaHyPE@LMU, TA2-55-1 Leonardo@CINECA

Hosting team: Thomas Ulrich (LMU), Iris Christadler (LMU), David Schneller (TUM), Giorgio Amati (CINECA), Piero Lanucara (CINECA)

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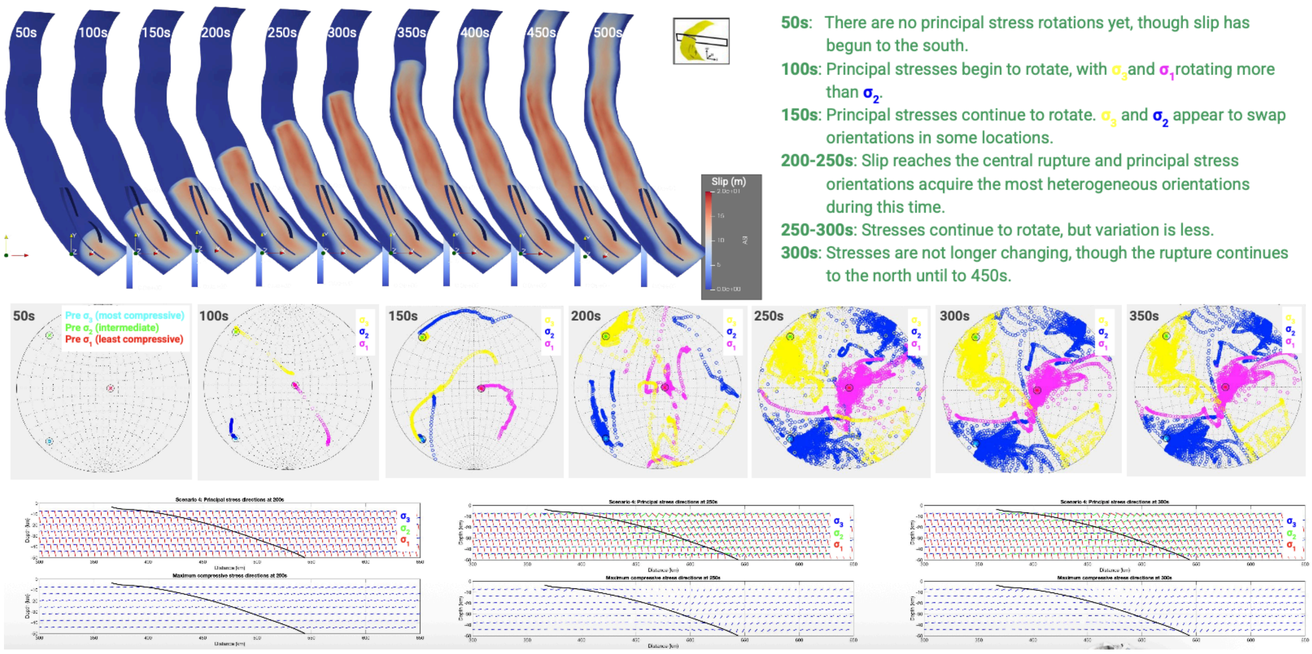
Report of activities:

During an earthquake, fault slip and the passing of seismic waves perturb the stress field surrounding the ruptured fault or faults. Aftershocks with a variety of focal mechanisms have been used to interpret a complete stress drop that has permitted principal stresses to swap orientations. We test if this is required or if aftershock heterogeneity may be promoted by moderate stress decreases and principal stress rotations, in the absence of a complete stress drop and principal stress swapping. Three-dimensional (3D) simulations of dynamic earthquake ruptures at high temporal resolution provide a pathway for testing these alternatives, but are challenged by the computational cost and storage space required to run and analyze such models at high enough spatial and temporal resolutions to study co-seismic stress evolution. We were supported by the Geo-INQUIRE Transnational Access program to run a suite of megathrust earthquake scenarios based on the 2004 Sumatra-Andaman earthquake on CINECA's Leonardo high performance computing (HPC) platform booster partition, currently ranked 10th in the Top500, the list of the fastest supercomputers in the world. These models are run with SeisSol, which solves for dynamic rupture on complex, three-dimensional faults and seismic wave propagation through heterogeneous media. Initial conditions for these scenarios vary in the amount of pore fluid pressure and how it is distributed with depth, the relative magnitudes of the principal stresses, and initial stress heterogeneity. As a result, the modeled earthquakes vary in magnitude, average stress drop magnitude, the distribution of stress drop along the main fault, and locations of peak slip and slip rate. We document the stress field at a central position along the rupture as it evolves from nucleation to earthquake end. Different relative initial stress magnitudes lead to different patterns of stress rotation during passage of the rupture front. While we continue to analyze the results for principal stress swapping, we find that, even when a complete stress drop is not achieved, stress rotations along the megathrust and in the hanging wall promote thrust, normal and strike-slip failure. Thus, though the results do not rule out complete stress drop and principal stress swapping as an explanation for aftershock heterogeneity, we find that stress rotations that occur along the megathrust and in the hanging wall support this, even when a complete stress drop is not achieved. These models push the limits of HPC experimental dataset storage, transfer and analysis. We utilize the new Geo-INQUIRE Simulation Data Lake (SDL), which provides not only capacity to store terabytes of synthetic data, but also allows open and FAIR (Findable, Accessible, Interoperable, Reusable) sharing of the results through Digital Object Identifiers (DOIs) for each dataset and the accompanying model files.

Project outcomes:

https://sdl.hpc.cineca.it/app/experiments/266/summary

Madden, E., Christadler, I., Ulrich, T., and Gabriel, A.-A.: *Earthquake rupture models with very high spatial and temporal resolution: Data management and insight into co-seismic stress evolution*, EGU General Assembly 2026, Vienna, Austria, 3–8 May 2026, EGU26-12706, https://doi.org/10.5194/egusphere-egu26-12706, 2026.



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