Exploiting exascale computing to unravel multi-physics and multi-scale earthquake dynamics and seismic wave propagation

*Alice-Agnes Gabriel[1], Bo Li[1], Duo Li[1], Thomas Ulrich[1], Carsten Uphoff[1]

1. Department of Earth and Environment Sciences, Ludwig-Maximilians-Universitat Munchen

Earthquakes are highly non-linear multiscale problems, encapsulating the geometry and rheology of propagating shear fractures that render the Earth’ s crust and emanate destructive seismic waves. Using physics-based earthquake scenarios, modern numerical methods and hardware specific optimisations sheds light on the dynamics, and severity, of earthquake behaviour.
The potential of in-scale earthquake rupture simulations for augmenting earthquake source observations is demonstrated in two recent examples: i) the 2016 Mw7.8 Kaikoura, New Zealand earthquake, considered the most complex rupture observed to date and causing surface rupture of at least 21 segments of the Marlborough fault system. High resolution dynamic rupture modeling [1] unravels the event's riddles in a physics-based manner; ii) the 2018, Mw7.5 Sulawesi earthquake occurring on the Palu-Koro strike-slip fault system sourcing an unexpected localised tsunami within Palu Bay [2]. The achieved degree of realism and accuracy in both examples is enabled by the open-source software SeisSol [3,4] which couples high-order accurate space-time solutions of wave propagation with frictional fault failure, off-fault inelasticity and viscoelastic attenuation.
I will discuss future directions for exploiting expected exascale computing infrastructure, specifically, representing complex geometries with novel geometric transformations and multi-physics by diffuse interfaces on adaptive cartesian meshes, thus avoiding manual meshing [5]. I will also touch on possibilities to go beyond earthquake scenarios unlocking the predictive power of forward simulations by a recently developed dynamic source inversion approach using a Bayesian framework and by statistical learning.

References

[1] Ulrich et al. (2019), “Dynamic viability of the 2016 Mw7.8 Kaikoura earthquake cascade on weak crustal faults”, Nature Comm., 10(1213), doi:10.1038/s41467-019-09125-w.
[2] Ulrich et al. (2019), “Coupled, Physics-based Modelling Reveals Earthquake Displacements are Critical to the 2018 Palu, Sulawesi Tsunami", PAGEOPH, doi:10.1007/ s00024-019-02290-5.
[3] Heinecke et al. (2014), “Petascale High Order Dynamic Rupture Earthquake Simulations on Heterogeneous Supercomputers”, SC14, 3–14. ACM Gordon Bell Prize Finalist. doi: 10.1109/SC.2014.6.
[4] Uphoff et al. (2017), “Extreme scale multi-physics simulations of the tsunamigenic 2004 Sumatra megathrust earthquake", SC17, Best Paper Award. doi: 10.1145/3126908.3126948.
[5] Reinarz et al., (2019), “ExaHyPE: An Engine for Parallel Dynamically Adaptive Simulations of Wave Problems", preprint at arXiv:1905.07987.

Keywords: Computational Seismology, Earthquake Rupture Dynamics, High Performance Computing