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Dynamic and quasi-dynamic modelling of earthquake sequences from zero to three dimensions: choose model complexity as needed

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Earthquake sequences reflect the repetitive dynamic processes of stress accumulation and release on a fault. Understanding earthquake sequences is fundamental for the research of induced and natural earthquakes and may ultimately help to better assess long-term seismic hazard. Numerical models are well-suited to overcome limited spatiotemporal observations and improve our understanding on this topic. However, large models in 3D are still computational time and memory consuming. Moreover, this may not be optimal if the aspects of lateral or depth variations within the results are not needed to answer a particular objective. This motivated us to investigate the advantages and limitations of various dimensional models by simulating earthquake sequences in 0D, 1D, 2D and ultimately 3D. We applied a C++ numerical library GARNET [1] to deal with the various dimensional models in one simulator. This library uses a fully staggered finite difference scheme with a rectilinear adaptive grid. It also incorporates an automatic discretization algorithm and combines different physical ingredients such as visco-elasto-plastic rheology and quasi- and fully dynamic approaches into one algorithm.

Here we present numerical experiments of a strike-slip fault under rate-and-state friction, surrounded by an elastic medium with constant tectonic loading and, test them under different parameters and initial conditions. By adding one dimension at a time, we simulate a more detailed structure of the seismic cycle. The higher dimensional models present both the validity and the limitations of the lower dimensional ones. For example, inertial waves are not possible to present in 0D while a quasi-dynamic radiation damping term can be added here instead. Another example is that due to lack of grid extension along the fault, both 0D and 1D model fail to reveal an earthquake nucleation phase. However, some important observables, such as the seismic cycle period, maximum/minimum stress and slip rates, are calculated accurately in lower dimensional models, which are much faster than higher dimensional models. We also implemented and compared quasi- and fully dynamic models in the same way. Our results indicate that both the size of simulated seismic events and their interval are reduced in quasi-dynamic models. This could provide us with guidance to identify the appropriate model complexity for various problems. We will also present 3D modeling results, which will be compared to their 2D equivalent. Finally, we present our results for the SCEC SEAS benchmarks [2] and compare them to other participating codes.

[1] Pranger, C. C., L. Le Pourhiet, D. May, Y. van Dinther, and T. Gerya (2016). "Self-consistent seismic cycle simulation in a three-dimensional continuum model: methodology and examples." AGU Fall Meeting Abstracts.

[2] Erickson, B. A., et al. (2019). The Community Code Verification Exercise for Simulating Sequences of Earthquakes and Aseismic Slip (SEAS). Poster Presentation at 2019 SCEC Annual Meeting.