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Characteristics of earthquake sequences: comparison from 0D to 3D

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Numerical models are well-suited to overcome limited spatial-temporal observations to understand earthquake sequences, which is fundamental to ultimately better assess seismic hazard. However, high-resolution numerical models in 3D are computationally time and memory consuming. This is not optimal if the aspects of lateral or depth variations within the results are not needed to answer a particular objective. In this study we quantify and summarize the limitations and advantages for simulating earthquake sequences in all spatial dimensions.

We simulate earthquake sequences on a strike-slip fault with rate-and-state friction from 0D to 3D using both quasi-dynamic and fully dynamic approaches. This cross-dimensional comparison is facilitated by our newly developed, flexible code library *Garnet*, which adopts a finite difference method with a fully staggered grid. We have validated our models using problems BP1-QD & FD and BP4-QD & FD of the SEAS (Sequences of Earthquakes and Aseismic Slip) benchmarks from the Southern California Earthquake Center.

Our results demonstrate that lower-dimensional/quasi-dynamic models are qualitatively similar in terms of earthquake cycle characteristics to their higher-dimensional/fully-dynamic counterparts, while they could be hundreds to millions times faster at the same time. Quantitatively, we observe that certain earthquake parameters, such as stress drop and fracture energy release, can be accurately reproduced in each of these simpler models as well. However, higher dimensional models generally produce lower maximum slip velocities and hence longer coseismic durations. This is mainly due to lower rupture speeds, which result from increased energy consumption along added rupture front directions. In the long term, higher dimensional models produce shorter recurrence interval and hence smaller total slip, which is mainly caused by the higher interseismic stress loading rate inside the nucleation zone. The same trend is also observed when comparing quasi-dynamic models to fully dynamic ones. We extend a theoretical calculation that to first order approximates the aforementioned physical observables in 3D to all other dimensions. These theoretical considerations confirm the same trend as what is observed for stress drop, recurrence interval and total slip across dimensions. These findings on similarities and differences of different dimensional models and a corresponding quantification of computational efficiency can guide model design and facilitate result interpretation in future studies.