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Earthquake Simulators: Statistical Methods, Fractal Faults and Forecasting

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SCEC Science Objectives: 4e, 2e, 3f

Abstract

We addressed the problem of developing and disseminating improved simulator technology using the Virtual Quake software platform. In the previous cycle we focused on the development of RELM-type forecast testing methods. We have continued to post/port codes to public code repositories such as CIG and GIT, along with improved documentation, so that colleagues can more readily use and test the codes under development. Most recently we have built a Docker Image that allows individuals to download and run the code easily, due to the inclusion of all necessary libraries, compilers and interpreters in the package. We have also examined and characterized faults using their fractal properties, and we continue to make progress in this area.

Science Nugget

- We developed fractal fault models that more realistically represent actual faults in Virtual Quake simulations. We expect that these more realistic models will significantly impact slip jump probabilities as well as other dynamical properties.

- We have improved the code so that the agreement between observed field and simulations is excellent (figure attached).

Science Highlights

1. Earthquake Simulators
2. Computational Science
3. Stress and Deformation Through Time (SDOT)

Exemplary Figures

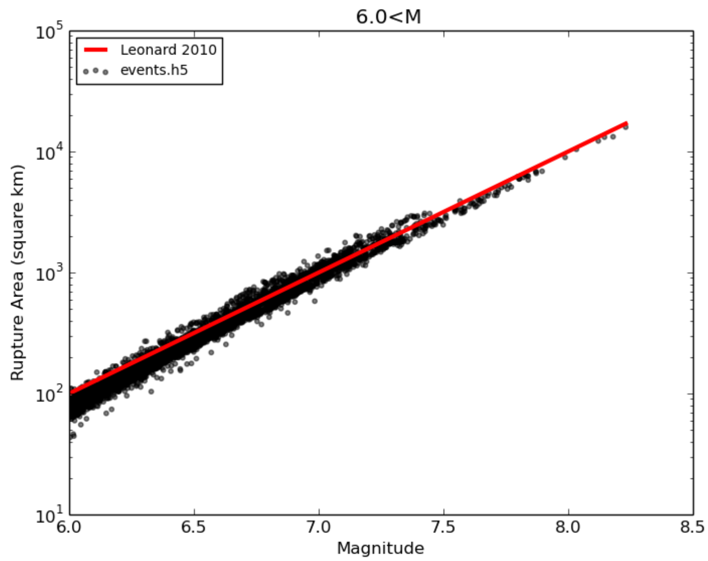

Figure 1. Agreement for scaling of rupture area vs. magnitude. Red line is dat from Leonard 2010, dots are from VQ simulations using UCERF3 fault model.

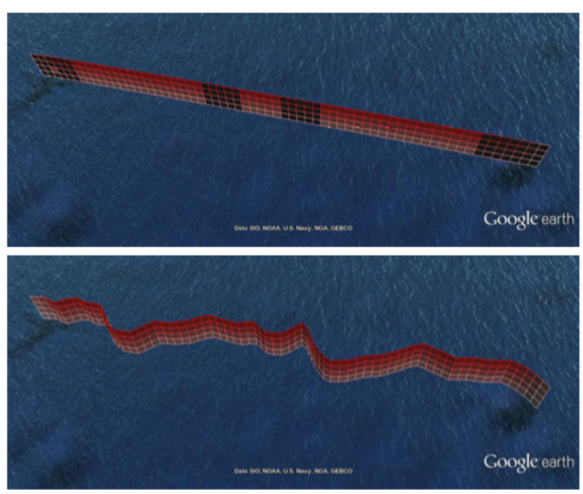

Figure 2: Google Earth visualization for (Top) a planar reference fault, and (Bottom) a fault with a trace with $\beta = 2$

Summary

Earthquake Simulators are computational simulations which attempt to mirror the topological complexity of fault systems on which earthquakes occur while including physical interactions such as friction and elastic stress transfer. These simulators are tuned so that they produce sequences of earthquakes that match natural earthquakes in known scaling properties. The great benefit of physically-based earthquake simulators is that they can generate many thousands of years of statistics for large, damaging earthquakes, which would otherwise have prohibitively long recurrence time scales for observation.

Virtual Quake is one such simulator. One strength of Virtual Quake is its modular design, allowing the fault model to be modified separately from the back- ground physics simulation. This easily allows the exploration of the effects of fault geometry on the resulting simulation statistics. Previous simulations of the California fault system treat fault segments as largely flat planes, while real faults demonstrate self-affine fractal structure (e.g., Power et al., 1987). This structure has an impact on the earthquakes emerging from such faults, serving as a limitation on the size of large ruptures and increasing resistance to slip. We document preliminary efforts to include this structure in Virtual Quake simulations.

Previous studies using physics-based simulators have modeled faults as relatively flat, planar surfaces. This geometry is conducive to rupture propagation, resulting in an artificially high number of large ruptures. Real faults, however, exhibit a deviation from the plane described by self-affine fractal statistics. Because of this detail, large ruptures can be inhibited from propagating to the entire fault (Wesnousky, 2006), and greater stresses can be accumulated before an initial slip occurs (Candela et al., 2012). These effects can change both the location of major earthquakes, as well as the proportion of moment release attributed to small verses large earthquakes.

In this years' research, we succeeded in incorporating fractal fault structure into the Virtual Quake simulator. We applied self-affine deviations to a idealized planar fault, and find that the resulting synthetic catalog matches observed earthquakes in chosen statistics better than the planar fault model.

References

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Power, W., Tullis, T., Brown, S., Boitnott, G., and Scholz, C. (1987). Roughness of natural fault surfaces. *Geophysical Research Letters*, 14(1):29–32.

Wesnousky, S. G. (2006). Predicting the endpoints of earthquake ruptures. *Nature*, 444(7117):358–360.

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Paper in Production Partially as Result of Grant

John Max Wilson, John B Rundle, and Donald L Turcotte, Effects of fractal roughness in Virtual Quake simulations, *to be submitted* (2017).