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Earthquake scaling laws for rupture geometry and slip heterogeneity

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We analyze an extensive compilation of finite-fault rupture models to investigate earthquake scaling of source geometry and slip heterogeneity to derive new relationships for seismic and tsunami hazard assessment. Our dataset comprises 158 earthquakes with a total of 316 rupture models selected from the SRCMOD database (http://equake-rc.info/srcmod). We find that fault-length does not saturate with earthquake magnitude, while fault-width reveals inhibited growth due to the finite seismogenic thickness. For strike-slip earthquakes, fault-length grows more rapidly with increasing magnitude compared to events of other faulting types. Interestingly, our derived relationship falls between the L-model and W-model end-members. In contrast, both reverse and normal dip-slip events are more consistent with self-similar scaling of fault-length. However, fault-width scaling relationships for large strike-slip and normal dip-slip events, occurring on steeply dipping faults ($\delta \sim 90\circ$ for strike-slip faults, and $\delta \sim 60\circ$ for normal faults), deviate from self-similarity. Although reverse dip-slip events in general show self-similar scaling, the restricted growth of down-dip fault extent (with upper limit of $\sim$200 km) can be seen for mega-thrust subduction events (M$\sim$9.0). Despite this fact, for a given earthquake magnitude, subduction reverse dip-slip events occupy relatively larger rupture area, compared to shallow crustal events.

In addition, we characterize slip heterogeneity in terms of its probability distribution and spatial correlation structure to develop a complete stochastic random-field characterization of earthquake slip. We find that truncated exponential law best describes the probability distribution of slip, with observable scale parameters determined by the average and maximum slip. Applying Box-Cox transformation to slip distributions (to create quasi-normal distributed data) supports cube-root transformation, which also implies distinctive non-Gaussian slip distributions. To further characterize the spatial correlations of slip heterogeneity, we analyze the power spectral decay of slip applying the 2-D von Karman auto-correlation function (parameterized by the Hurst exponent, H, and correlation lengths along strike and down-slip). The Hurst exponent is scale invariant, H = 0.83 ($\pm$ 0.12), while the correlation lengths scale with source dimensions (seismic moment), thus implying characteristic physical scales of earthquake ruptures. Our self-consistent scaling relationships allow constraining the generation of slip-heterogeneity scenarios for physics-based ground-motion and tsunami simulations.