Multiscale Heterogeneities in Earthquake Source Processes

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Earthquakes are scale-free phenomena in general, governed by scale-independent parameters and laws, such as stress drop, rupture propagation velocity, the Gutenberg-Richter law, and the Omori law. Despite their complexity, earthquake rupture processes are spatially and temporally characteristics to some extent, and the location, size, and timing of rupture are not completely random. These two aspects of earthquakes suggest the existence of time-independent hierarchical structures in earthquake source regions. Ide and Aochi (2005) proposed a hierarchical earthquake model comprising a fractal set of randomly distributed circular patches, with fracture energy proportional to patch radius. This model produces a statistically self-similar cascading rupture sequence from a tiny patch. The rupture process is complex, and propagation velocity is variable: it can locally exceed shear wave velocity, but remains sub-shear on average. The cascading rupture model explains the complex rupture process of the 2011 Tohoku-Oki earthquake, using a patch distribution based on previous earthquake locations.

In subduction zones, the statistical features of seismicity vary regionally, and we have identified that some of these variations are responsible to different tectonic factors. The number of background earthquakes is controlled mainly by relative plate velocity, with a significant effect due to plate geometry. The b-value of the Gutenberg–Richter law, which is strongly related to the hierarchical structure, shows a clear dependence on plate age. These variations are probably related to the nature of slow deformation, such as tectonic tremors, slow slip events, and any process below the noise level. In some regions, tremors are clearly modulated by small tidal stress and a rate-dependent friction law. The modulation of slow deformation by such small stress suggests that various kinds of stress sources would change the underground stress and strain and prepare the occurrence of ordinary earthquakes.