Geophysical Research Abstracts
Vol. 21, EGU2019-4604, 2019
EGU General Assembly 2019

Relation between heterogeneity of frictional property and complexity of earthquake cycles

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Numerical simulations are conducted to examine the effect of heterogeneity of frictional property on earthquake cycles. Rate- and state-dependent friction is assumed on a planar fault in an infinite uniform elastic medium. One to four circular patches of steady-state velocity-weakening frictional property is assumed on the model fault plane, and velocity-strengthening friction is assumed outside the circular patches. Friction parameters are uniform within each patch, and the values of characteristic slip distance L in the patches are varied so that the effect of interaction between the patches with different frictional property may be examined. Simulation results indicate that simple periodic (period-1), multi-periodic (period-n, n > 1), and aperiodic earthquake cycles occur in the models. Here, a period-n cycle indicates that n different slip events are included in a cycle. In the one-patch model, simple periodic earthquake cycles occur for smaller L, where the critical nucleation radius h*, which is proportional to L, is smaller than the radius of the velocity-weakening patch, and multi-periodic and aperiodic sequences of slip events occur for larger L, where the patch radius is close to h* (Kato, 2014, Geophys. J. Int., 198, 727-736). In the two- to four-patch models, a patch is ruptured in some cases and some or all patches are simultaneously ruptured in the other cases. This causes complex earthquake cycles. Slip events of different combinations of patches occur. The possible number of combinations is larger for larger number of patches on a fault. Moreover, aseismic slip events occur within velocity-weakening patches with larger L, which also complicates sequences of slip events. Even in a velocity-weakening patch whose radius is smaller than h*, seismic slip may occur because it is triggered by seismic slip nucleated in another patch. In a parameter study where the characteristics of earthquake cycles are examined with a change in L in a patch, we find that earthquake cycles can be classified into several patterns according to the combination of ruptured patches in earthquakes. Complex aperiodic earthquake cycles tend to occur in a parameter range between parameter ranges of different patterns. Frequencies of multi-periodic and aperiodic earthquake cycles increase with the number of velocity-weakening patches, suggesting that more complex cycles may be generated in a fault with more heterogeneous frictional property. Frequency distribution of recurrence intervals of simulated earthquakes is discrete in the single-patch model and it becomes more continuous and realistic with an increase in the number of patches. These simulation results suggest that realistic complex earthquake cycles are caused by interaction among many patches of different frictional property.