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Implications of seismic cycle simulations for earthquake forecasts: A review and perspective

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Laboratory-derived friction laws such as rate- and state-dependent friction laws have been used in numerical simulations of seismic cycles because they take into consideration restrengthening of faults as well as rate dependence of friction. The simulated seismic cycles mimic characteristics of recurrence of historical interplate earthquakes estimated from various observations, and provide mechanical explanations for various phenomena such as afterslip and slow earthquakes. Recent seismic and geodetic observations indicate that stick-slip occurs at asperities and aseismic sliding occurs at the other places. This difference in sliding behavior can be reproduced in the simulations and the difference in sliding behavior can be expressed by the difference in values of constitutive parameters. Moreover the interactions between unstable slip at asperities and aseismic sliding have been examined in the numerical simulations. Thus the simulations are useful for understanding various observations about sliding behavior on plate boundaries.

On the other hand, it is not clear that the models on the basis of laboratory-derived friction laws are useful for earthquake forecasts. The models predict the occurrence of preseismic sliding, and this is a physical basis of short-term earthquake prediction. However, the magnitude of preseismic sliding depends on constitutive parameters, which cannot well be constrained from available data. The numerical forecast of earthquakes like that of weather is one of the final goals of the study. There are several problems for the numerical forecast of earthquakes as follows: (1) Constitutive laws are not accurate. The rate- and state-dependent friction laws are simple with a few parameters and well describe some important characteristics of rock friction, and they successfully explain various phenomena in the lab and in the earth. However, the friction laws cannot fit some experimental data, and their applicability to the seismic cycles is not clear. (2) The initial values of stresses and sliding velocities on the plate boundary for numerical simulations cannot exactly be measured. (3) It is difficult to accurately estimate constitutive parameters on the plate boundary. Some researches comparing geodetic and seismic observations with simulations are in progress to determine the parameters. (4) Interaction between many earthquakes and slip events complicate seismic cycles. This makes deterministic forecasts difficult in principle.

In the next five years, monitoring spatio-temporal variation of slip on the plate boundaries and the evaluation of the monitored data through the comparison with the simulations are important to understand stressing of asperities and forecast future crustal activities. These studies of the comparison between the observations and the simulations are also useful for evaluating the validity of constitutive laws of friction and for estimating constitutive parameters. To this end, methods for systematic comparison between the observed data and simulations must be developed. Using such methods it may be possible to estimate the range of initial and parameter values that are consistent with given data. Moreover, we have to attempt to perform experiments of forecast simulation for regions where large or moderate earthquakes are expected to occur in near future. Through the simulation experiments, we will investigate what kinds of data are necessary to determine model parameters and reduce errors in forecasting sliding behavior. Statistical forecasts of earthquakes when many asperities or fault segments interact with one another are challenging subjects. Numerical simulations are useful to study the effect of interactions on irregularity in earthquake recurrence.