Temporally variable estimation of friction parameters using machine learning

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Earthquakes occur due to frictional stick-slip instabilities on faults (e.g., Scholz, 1998), thus knowing the behavior of friction on a fault is important to understand the earthquake occurrence process. The rate-and-state dependent friction law (e.g., Dieterich, 1979, JGR) is widely used to model laboratory observations of rock friction. The law is characterized by three friction parameters, *a*, *b* and the critical slip distance *Lc*, which are usually considered time independent. Urata et al. (2017, PAGEOPH) estimated these parameters by using simulations that reproduce the stick-slip event occurrence in a biaxial rock friction experiment. The results show that the friction parameters may change as slip progresses. In this study we estimate temporally variable friction parameters using a machine learning approach. Our final goal is to propose a new friction law that can account for the temporally variable friction parameters. We consider such intrinsic variability to be primarily a consequence of changes in the fault rock environment conditions during repeated stick-slip.

The experiment data and simulation method of this study are the same as in Urata et al. (2018). The simulations of a spring-slider model with one-degree-freedom are used as the training dataset for our machine learning algorithm to estimate the friction parameters based on the experiment data. Machine learning enables us to reduce the calculation costs when dealing with large datasets and predict parameters more accurately. We employed the random forest algorithm (Breiman, 2001, Machine Learning), which is also used in other earthquake related studies (e.g., Rouet-Leduc et al., 2017, GRL). The algorithm is known for its accuracy, despite its simple formulation, and the capability to account for multiple variables. In order to quantify the temporally-dependent friction parameters, we set time windows spanning from one stick-slip event to the next and estimate the parameters in each time window. We finally predict the parameters *b* and *Lc* out of the three friction parameters (the *a* parameter is considered a material constant), using the experiment data. The steps used in the estimation are presented in detail below.

We first obtain two relationships of shear-stress divided by normal stress with respect to time and slip, for each time window, using the simulation data and calculate window-length (i.e., duration of a stick-slip event), variance, skewness and kurtosis corresponding to each time window. We associate this dataset, consisting of seven values for each time window, to the combination of parameters *b* and *Lc* used in the simulation. The parameters *b* and *Lc* are taken from a grid of 50x50 values that sample a large range of parameter values. The same seven values are also estimated from the observation data, for successive stick-slip events in the rock friction experiment. Finally, the *b* and *Lc* are estimated (predicted) from the experiment data, using a random forest decision tree and the training dataset from simulations.

Our predicted *b* and *Lc* values agree in general with those estimated by Urata et al. (2017). The evolution of *b* and *Lc* are connected one with each other. The *b* parameter has relatively slow changes, while the *Lc* variations are rapid. We could not find a clear temporal trend yet in the data for a 18-second interval analyzed in this study, as we would have expected based on simple physical considerations (i.e., gradual increase of parameters *b* and *Lc* with increase of strength on the fault when stick-slip events occur repeatedly and the gouge layer on the fault becomes thicker). However, we may be able to get significant environment-dependent friction parameters when parameter estimation will be conducted using experiment data for longer time intervals.