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# データ同化手法による断層すべり数値モデルの状態・パラメータ推定
# State and parameter estimation of numerical models of fault slip using data assimilations methods

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Numerical models of the evolution of fault slip based on rate- and state-dependent frictions laws have been widely used to simulate variety of seismic and aseismic fault slip behavior during the earthquake cycle, including earthquakes, afterslip, slow slip events, and steady aseismic creep. These numerical models consist of the equations of motion and friction law for many subdivided fault patches and include parameters that describe frictional properties of the fault. Previous numerical studies have shown that these parameters, which are often called friction parameters, as well as initial conditions of the model, are one of the governing factors in determining the evolution of fault slip. However, it has been difficult to constrain the friction parameters and initial conditions for natural faults. In this study, we develop methods to simultaneously estimate the friction parameters and initial conditions of the model based on data assimilation methods.

We focus on afterslip, which is transient, decelerating, aseismic slip triggered by stress changes due to a large earthquake. We assume cumulative slip is observable and generate simulated data using the numerical model. A nonlinear state space model is used to relate the numerical model and observations to unknown parameters and dependent variables of the model.

We first adopt the particle filter and smoother to estimate probability distributions of the parameters and dependent variables of the model. In this case, the particle filter/smoother tends to degenerate even if a simplified model and relatively a large number of particles are employed, suggesting that it is difficult to correctly estimate the probability distributions of the unknowns with the particle filter/smoother. We then adopt the ensemble Kalman filter and smoother. We find that the ensemble Kalman filter/smoother does not degenerate even if the number of particles is small, indicating that this method is useful for our problem.

Our results indicate that our methods reproduce the true parameter values reasonably well if the initial conditions are fixed to the true values. In contrast, if the initial conditions are treated as unknowns, the state variable in the rate-state friction law cannot be constrained. In addition, the estimated friction parameters exhibit large uncertainties and a systematic bias. These results suggest that there are significant trade-offs between the friction parameters and initial conditions. We will discuss the details of the results, considerations on how to overcome the trade-offs, results from other data sets, and detailed comparisons of the two methods in the presentation.

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