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EnKF Estimation of Frictional Properties and Slip Evolution on a LSSE Fault -Numerical Experiments-

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There have been observed a variety of SSEs (Slow Slip Events) in the up- and down-dip portions of the megathrust fault regions. Activities of these SSEs are sensitive to external stress perturbations, which can be stress meters for monitoring the stress state of megathrust faults toward the next breaks. In this study, we develop a method for estimating frictional properties and for real-time monitoring slip evolution on LSSEs, by applying a sequential data assimilation method, EnKF (Ensemble Kalman Filter), which has been developed in atmosphere and ocean sciences. For this purpose, we execute numerical experiments for the Bungo Channel LSS on the Philippine Sea plate interface in southwest Japan, whose duration and recurrence interval are 1 and 6 yrs.

First, based on a RSF law with the aging law (Dieterich [2018]), we set a rate-weakening (A-B<0) circular patch in the rate-strengthening (A-B>0) stable flat plate interface, where the critical nucleation size (Rubin and Ampuero [2005]), is larger than the patch size, reproducing the observed Bungo Channel LSSEs. Then, we synthesize observed data of surface displacement rates at uniformly distributed stations with noises from the simulated slip model and perform EnKF estimations of the frictional parameters A and L on the fault and B-A on the patch along with the evolution of slip rates and the state variables. In contrast to our previous studies (e.g. Okuda [2016]), as initial ensemble members, we select several pairs of frictional parameters in a wide range of parameter space which reproduce LSSEs. Then, we successfully estimate frictional parameters and slip evolution after short cycles, indicating that the result is not much dependent on the initial ensemble members.

Second, we consider the effect of megathrust fault region, which exists in the up-dip portion of the LSSE region on the plate interface, as revealed by kinematic inversion studies of GNSS data. We add a locked region in the model and include the slip rate in the state vector. We estimate the slip rate on the locked region only kinematically, but the quasi-dynamic equation of motion in each LSSE fault cell includes the stress term arising from the locked region, which produces an asymmetric slip evolution pattern of LSSE, as suggested by Nakata et al. [2017]. Based on this LSSE model with the locked region, we synthesize the observed surface displacement rate data at the actual GEONET stations. Then, again, we perform EnKF estimations of the slip rate on the locked region, in addition to frictional parameters, slip rates and state variables on the LSSE fault with the above stated strategy for assignment of initial ensemble members. The slip rate on the locked region can be quickly retrieved. Even for the actual GEONET stations, we can successfully estimate frictional parameters and slip evolution on the LSSE fault, though the convergence is slower than that for the ideal stations just above the LSSE fault.

Now, we assume the constant slip rate on the locked region. The locking state of the megathrust fault is, however, possibly changing before the next break. Our formulation can monitor the slip state on megathrust and LSSE faults sequentially, considering the stress interaction from megathrust to LSSE faults.