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 shallower and deeper 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 respect, it is important to understand fault properties on SSE faults and to monitor their activities. In this study, we develop a method for estimating frictional properties and for real-time monitoring slip evolution on LSSEs (Long-term SSEs), by applying a sequential data assimilation method, EnKF (Ensemble Kalman Filter), which has been developed in atmosphere and ocean sciences. Therefore, we execute numerical experiments for the Bungo Channel LSSE on the Philippine Sea plate interface in southwest Japan, whose duration and recurrence interval are 1 and 6 yrs.

First, based on a RSF(Rate and State Friction) law with the aging law, 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 is larger than the patch size, reproducing the observed Bungo Channel LSSEs . Then, we synthesize observed data of surface displacement rates with noises from the simulated model, and perform EnKF estimations of the frictional parameters A and L on the fault and B-A on the patch along with the slip rates and the state variables in the state vector. In our previous studies, we assigned a set of initial ensemble members around a pair of frictional parameters. The result depends on the initial assigned values, or numerical instability occurs to fail innovation. Therefore, 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 is located just above the LSSE region on the plate interface, as shown by kinematic inversion studies of GNSS data. We add a locked region above the LSSE fault region in the model and include the slip rate in the state vector. We estimate the slip rate on the locked region kinematically, but the quasi-dynamic equation of motion in each LSSE fault cell includes the stress term arising from the locked region. Based on this Bungo Channel LSSE model with the locked region, we synthesize the observed displacement rate data at the surface in 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. There remain several problems for actual GEONET data analyses. First, we use the displacement rates for observational data. The actual GNSS data provide daily positions with the accuracy of mm and we need to devise some smoothing for obtaining rates. Second, we use a simple flat LSSE fault here, and we need to

consider the curved fault on the subducting Philippine Sea plate interface. Finally, we use a simple frictional model. We need to consider the heterogeneous distributions of frictional parameters and locked states.

Keywords: Ensemble Kalman Filter, Long-term slow slip event, Rate and state friction, Megathrust earthquake

