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Robust estimation of spatio-temporal distribution of slow slip event by switching model

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Short-term slow slip event (SSE) can be precisely captured by only highly sensitive instruments such as borehole strainmeter and tiltmeter, Meanwhile, since such sensitive instruments is affected by various external factors, the observed data contain large noise which has complicated structure in time.

We estimate the spatio-temporal distribution of SSE by analyzing noisy data such as strain data and tilt data. Conventionally, the Network Inversion Filter (NIF) has been widely used to estimate the spatio-temporal distribution of the larger SSE, e.g., long-term SSE, based on smaller noise data such as Global Navigation Satellite System (GNSS). However, since the NIF assumes the same dynamics of the noise and slip signals over the entire observation period, the NIF cannot eliminate the large noise signals from such noisy data. Therefore, the NIF cannot correctly estimate SSE from the entire period of the noisy strain and tilt data.

We propose the estimation method using the switching model that represents three forms in three periods. In the first period, the fault never slips, in the second period, the fault is slipping slowly, and in the third period, the fault is being at rest. The time points at which the model changes as well as the parameters of the switching model are estimated by the maximum likelihood method using the Expectation-Maximization (EM) algorithm. The EM algorithm maximizes the likelihood with little dependency on initial parameters and enables us to estimate the parameters stably. The spatio-temporal distribution of SSE is estimated using the Kalman filter, after the model changing time points and the parameters of the model are estimated. The strict and physically reasonable assumptions of the fault slip in first and third periods remove the almost noise signal in the periods, and lead to the stable estimate of the fault slip in the second period.

In order to compare the proposed method to the NIF, we applied the proposed method and the NIF to the noisy synthetic data and the strain data. The synthetic data were produced by the simulation of SSE and large noise signals, and the strain data were measured in the Tokai and Kii area, central Japan, on 2012. In the synthetic data, the fault slip estimated by the proposed method is much more accurate than that by the NIF. The proposed method also estimated the more reasonable SSE than the NIF in the strain data. It is important to detect the starting time point of SSE without any information, and the proposed method correctly detected the starting time point of SSE in both data sets, which the NIF could not capture.

Keywords: Slow slip event, Strain data, Switching model, Maximum likelihood method, Kalman filter