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Numerical simulations of slow slip events and the stress build-up and nucleation process of a large earthquake

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Recent studies have revealed that the various types of slow events have occurred on a subducting plate around the depth of 30 km: slow slip events (SSEs), very low frequency earthquakes (VLFEs), and low frequency tremor/earthquakes. Geodetic observations of SSEs are well explained by the slip on the plate interface (e.g. Hirose and Obara, 2005). Focal mechanisms of VLFEs and low frequency earthquakes are also consistent with the subducting direction of the Philippine Sea plate (Ide et al., 2007; Ito et al., 2007). Therefore, those slow events are interpreted as slip phenomena on the plate interface. SSEs in southwest Japan are classified to two types by the recurrence interval: i.e., long-term SSEs (L-SSEs) and short-term SSEs (S-SSEs). L-SSEs have a recurrence interval of several years, and are found only in the Tokai region and the Bungo channel region. S-SSEs have an interval of several months and are found along the belt-like distribution of low frequency tremor (Obara, 2002). In our previous numerical study, we simulated the interaction only between L-SSEs and S-SSEs, and did not consider the effect of the shallower extent where the plate interface is coupled (i.e. a large earthquake is expected). In this study, we evaluated the effect of stress build-up process at coupled region on the slow slip behavior.

We numerically simulated the SSEs and inter-plate earthquakes on both 1- and 2-D flat fault planes in a semi-infinite elastic medium. We used a rate- and state-dependent friction law with a cut-off velocity as adopted by Shibazaki and Shimamoto (2007). We assumed that pore pressure approaches to lithostatic pressure from the depth of 24 km to 28 km, and becomes constant below 28 km (i.e. effective normal stress becomes very low at such region). Hereinafter, we call this model as S-SSE model. Kodaira et al. (2004) and Matsubara et al. (2008) suggested that dehydration process of the subducting plate starts shallower at L-SSE region than the surrounding. We also assumed another model (L-SSE model) that pore pressure becomes high at the shallower depth of 26-28 km than those in S-SSE model.

In the case of L-SSE model with a 1D-fault, SSEs repeatedly occur with the interval of 7-9 years. The recurrence interval of SSEs becomes shorter (about 7 years) before a large earthquake occurs in coupled region, and then becomes longer (about 9 year) after the large earthquake. The slip region of simulated L-SSEs extends to the shallower part of the plate at the later stage in inter-seismic period of large earthquakes. Slip velocity increases just before large earthquakes at the depth of 22-26 km, where slip behavior changes from fast slips to slow slips. In the case of S-SSE model with a 1D-fault, SSEs occur at the interval of 3-7 months. The recurrence interval also becomes shorter as the occurrence of large earthquake approaches.

In 2D-fault model, we assumed S-SSE model with a patch region of L-SSE model which has 20 km-width in horizontal direction. In this case, the recurrence interval of L-SSEs becomes shorter as the stress is accumulated. The recurrence interval of S-SSEs becomes shorter near the occurrence of an L-SSE, as observed by Hirose and Obara (2005).

The behavior obtained in this study, however, is based on one possible model of SSEs. Though the shortening of the recurrence intervals seems to be related to the stress build-up and the slip at the bottom of coupled region, it is important to evaluate which model is adequate in such region, incorporating the further study in geophysical observations and rock experiments. If a rate-and state-dependent friction law is valid in this region, it may be possible to estimate the stress-build up process on a plate interface by the monitoring of SSEs.