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Numerical modeling of slow slip events during seismic cycles of megathrust earthquakes

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Recent studies have revealed the episodic occurrence of low-frequency tremor and slow slip events (SSEs) in several subduction zones. In the Nankai subduction zone, SSEs are classified into short- and long-term SSEs, according to the duration of slipping. Short-term SSEs have duration of several days and recur at the intervals of several months. These short-term SSEs are found with very active tremor. On the other hand, long-term SSEs have duration of more than several months and recur at intervals of several years. In the Nankai subduction zone, long-term SSEs are found only in the Bungo channel and the Tokai region. The recurrence intervals of short-term SSEs shorten during the long-term SSE in the Bungo channel (Hirose and Obara, 2005). The SSEs are interpreted as an episodic slip event at the deeper extent of the strongly coupled plate interface (i.e., locked region), where large inter-plate earthquakes occur at the interval of 100-200 years. This suggests that the repeating SSEs may cause stress accumulation at the bottom of the locked region. In this study, we numerically reproduce short- and long-term SSEs in seismic cycles, to evaluate the interaction between the behavior of SSEs and the stress build-up on a plate interface.

In our numerical model, we consider a subducting plate interface dipping at 15 degrees in a 2D and 3D semi-infinite elastic medium. The plate interface is divided into rectangular cells. Temporal evolution of the slip velocity on the cells is calculated incorporating the frictional stress on each cell and the elastic interactions between cells. We adopted a rate- and state-dependent friction law with cut off velocities. Small cut off velocity for the evolution effect is assumed at the SSE regions to reproduce slow slip velocity, as in Shibazaki and Shimamoto (2007).

In the SSE regions, existence of fluid is suggested by several studies (e.g., Shelly et al., 2006). This implies that the effective normal stress may be low at SSE regions, due to high pore pressure. In 2D models, we examine two different distributions of effective normal stress to reproduce long- and short-term SSEs separately. In the short-term SSE model, effective normal stress starts to decrease from the depth of 24 km. In the long-term SSE model, effective normal stress is kept slightly higher at the depth of 27-30 km than that in the short-term SSE model. In a 3D model, we assumed short-term SSE model with a patch region of long-term SSE model which has 30 km-width in horizontal direction (Figure 1).

In the 2D models, SSEs recur at the interval of 7-9 years and 3-7 months for the long- and short-term SSE model, respectively. In addition, large earthquakes recur at the interval of about 110 years. Both models show that the recurrence intervals of SSEs shorten as the next large earthquake approaches. In the 3D model, long- and short-term SSEs are successfully reproduced within a single model. The intervals of short-term SSEs shorten during long-term SSEs, as observed in actual SSEs (Hirose and Obara, 2005). The intervals of short- and long-term SSEs also shorten as a large earthquake approaches (Figure 2). The bottom of the locked region gradually migrates upward in a seismic cycle, reflecting the stress build-up by the SSEs and stable sliding.

Finally, a large earthquake nucleates at the bottom of the locked region. Our numerical results suggest that SSEs may work as an indicator of stress build-up prior to a large earthquake, although further investigation of SSEs are essential to evaluate whether our models are valid in such a region.

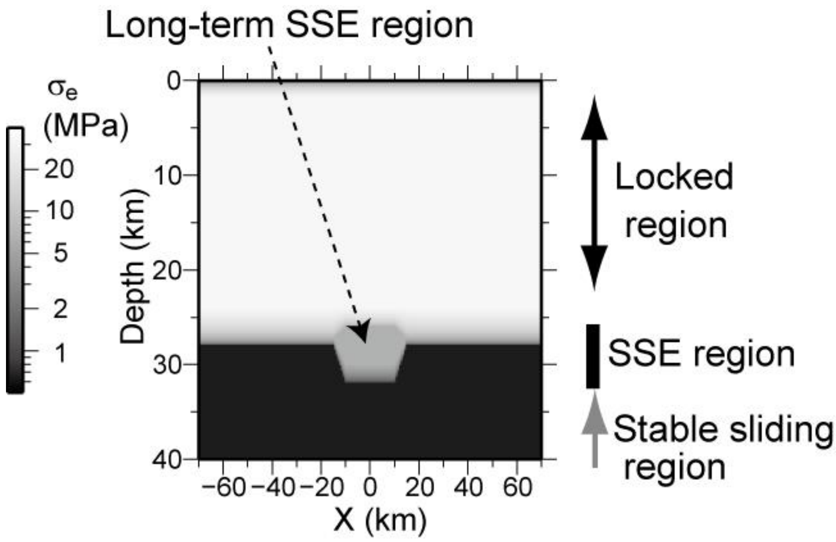

Figure 1. Distribution of effective normal stress (σ_e) in the 3D model. Long-term SSE region locates at the center of the modeled region at the depth of around 30 km. Short-term SSE region is outside of the long-term SSE region at the depth of around 30 km.

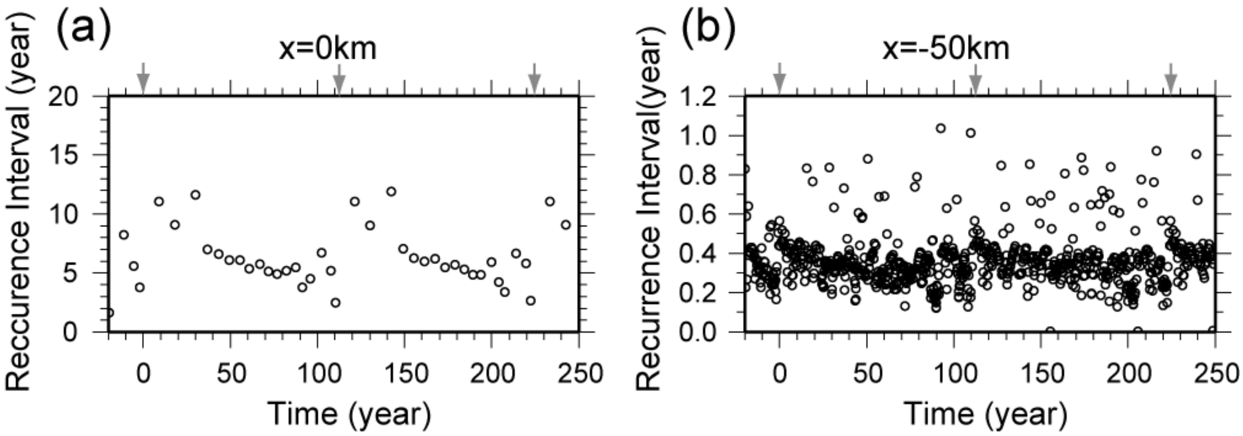

Figure 2. Recurrence intervals of SSEs in a 3D model. Occurrences of large earthquakes are indicated by gray arrows. (a) Intervals at the long-term SSE region. (b) Intervals at the short-term SSE region.