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Numerical modeling of slow slip events during the seismic cycles of megathrust earthquakes in the Kii and Tokai region

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Slow slip events (SSEs) and deep low-frequency tremors have been found in several subduction zones. These events are interpreted as slip on the plate interface based on geodetic observations of SSEs and focal mechanisms of low-frequency earthquakes (e.g. Hirose and Obara, 2005; Ide et al., 2007; Ito et al., 2007, 2009). As recent studies start to reveal the details of tremor and SSE activities (Obara, 2010; Hirose et al., 2010), a numerical model is necessary to interpret those observations and understand the stress state at the deeper extent of the major slip region of megathrust earthquakes. Our previous study (Matsuzawa et al., 2010) reproduced long- and short -term SSEs during seismic cycles of megathrust earthquakes, assuming a flat fault model. The simulated result suggests that the recurrence interval of SSEs shortens in an inter-seismic period, and implies that the continuous observation of SSEs is important to understand the occurrence of megathrust earthquakes. In this study, we reproduced and examined the occurrence of short-term SSEs and megathrust earthquakes introducing the shape of the subducting plate in the Tokai and Kii region.
We modeled a plate interface within a semi-infinite elastic medium, and calculated the temporal evolution of slip, assuming a frictional constitutive law and loading velocity on the interface. Adopting the numerical method of Shibazaki et al. (2010), we make a large scale simulation which includes seismic cycles of megathrust earthquakes. Although several models are proposed to reproduce SSEs (e.g. Rubin, 2008), we adopted a rate- and state-dependent friction law with cut-off velocities (e.g., Shibazaki and Shimamoto, 2007; Matsuzawa et al., 2010). The distribution of friction parameters is given by the function of depth, which is the same in Matsuzawa et al. (2010). Low effective normal stress (i.e. high pore pressure) is assumed in the occurrence region of SSEs. The plate interface is expressed by 40000 small triangle elements based on the result of Shiomi et al. (2006) and Baba et al. (2006). We assume that loading velocity gradually changes from 3 cm/year in the Tokai region to 6 cm/year in the Kii region, based on Heki and Miyazaki (2001).
Our numerical result successfully reproduced megathrust earthquakes and repeating SSEs. The recurrence intervals of the SSEs are 2-3 months and 3-4 months, in the northern Kii and Tokai region, respectively. The propagation of SSEs is interfered by the topography of the plate interface. For example, a ridge-like shape below Ise Bay works as a major barrier to SSEs. Some large SSEs propagate over the Ise Bay region. This is similar to the large SSE observed in 2006 (Obara and Sekine, 2009). In addition, recurrence intervals of the SSEs decrease during an inter-seismic period, as found in the case of a flat fault plane (Matsuzawa et al., 2010).
In our result, segmentation of the SSE source areas is reproduced by introducing the actual shape of the plate interface. As suggested in Shibazaki et al. (2009), this segmentation is affected by the width of SSE region in the dip direction. Shortening of the recurrence intervals may reflect the upward migration of the bottom of the locked region during an inter-seismic period, as discussed in Matsuzawa et al. (2010). In the early stage of a seismic cycle, recurrence intervals of SSEs are relatively long as the locked region is close to the SSEs. In the later stage of a seismic cycle, recurrence intervals of SSEs are likely to shorten reflecting accelerated slip velocity above the

SSE region as the bottom of the locked region migrates upward by the stress concentration. Although this model successfully reproduced some of important characteristics of the real SSEs, this is just one of possible models. It is significant to examine the assumptions in the simulation, based on the observations and experiments about the slip and frictional behavior below the major slip region of megathrust earthquakes.

Keywords: Slow Slip Event, Seismic Cycle, Numerical Simulation, Subduction Zone, Kii and Tokai