# Numerical modeling of slow slip events in a seismic cycle considering the effect of earth tides and the configuration of subducting plate in the Shikoku region

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It has been reported that earth tides affect the activity of episodic tremor and short-term slow slip events (hereinafter, short-term SSEs) in Nankai and Cascadia (e.g., Nakata et al., 2008; Rubinstein et al., 2008; Ide and Tanaka, 2014; Yabe et al., 2015). The tidal effect on the SSEs is also examined by numerical studies (e.g., Hawthorne and Rubin, 2013). In our previous study, we suggested the recurrence intervals of SSEs become shorter in the late stage in seismic cycles of megathrust earthquakes (Matsuzawa et al., 2010). In addition, short-term SSEs recurring in the Shikoku region, Japan, were numerically reproduced in our previous study, incorporating the actual plate configuration and SSE region (Matsuzawa et al., 2013). In this study, we examined the behavior of short-term SSEs in the Shikoku region in a seismic cycle of megathrust earthquakes, considering stress perturbation by earth tides.
Our numerical model is similar to our previous study (Matsuzawa et al., 2013). The interface of the subducting Philippine Sea plate is expressed by 93,144 small triangular elements. A rate- and state-dependent friction law (RS-law) with cutoff velocities is adopted as the friction law on each element. We assumed that (a-b) value in the RS-law is negative within the short-term SSE region, and positive outside the region. The short-term SSE region is based on the actual distribution of deep low-frequency tremor. Low effective normal stress is assumed at the depth of short-term SSEs. We assume that the stress change by earth tides is represented by periods of 10 major tides, calculating stress change as in Yabe et al. (2015). Incorporating this stress perturbation, we calculate the evolution of slip on the plate interface.
In the numerical result with the effect of earth tides, recurrent intervals of SSEs at the relatively isolated SSE region in the eastern Shikoku have smaller fluctuation than the case without tidal effect. For example, standard deviation of recurrence intervals between 5 and 20 years after the first megathrust earthquake are 0.00037 years and 0.00062 years in the isolated SSE region at the northeastern Shikoku, with and without the case of earth tides, respectively. In addition, we also examined the case only with the Mf tide which has the period of about half months. In this case, the fluctuation is slightly smaller than the case without tides, while the fluctuation is larger than the case with 10 major tides. This shows that long-period tides can also affect the recurrence of SSE, even though the amplitude of stress change by the Mf tides is about 10 Pa and about $10^{-1}$-$10^{-2}$ times smaller than the amplitudes of major semidiurnal and diurnal tides (i.e., M2, S2, O1, and K1 tides).. Introduction of tidal effect also makes peak velocity faster than that in the case without tidal effect. For example, peak slip velocity averaged between 5 and 20 years increases 3.5% and 8.5% in the northeastern region and the western Shikoku region where SSE regions are largely connected, respectively.
At the later stage in a seismic cycle, the recurrence interval tends to show larger fluctuation even in the relatively isolated SSE region. This may be caused by the long-term SSEs occurring in the updip of the short-term SSE region, as long-term SSEs are more frequently occur at the later stage in a seismic cycle in our numerical simulation. In the case with earth tides, averaged recurrence intervals still becomes slightly shorter in these SSE regions at the later stage in a seismic cycle, as suggested in Matsuzawa et al. (2010).

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