The slow slip event in the Tokai region, central Japan, since 2013 as seen from GPS data

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Advent and developments of continuously operating dense GPS arrays have enabled us to detect aseismic transient slow slips called as slow slip events (SSE) that occur along the subducting plate interface. SSE has been discovered in Bungo Channel, Boso Peninsula, Tokai region and Ryukyu region in Japan. Moreover, short term SSEs have been found using the data of tiltmeters in the Hi-net seismic network in the southwestern Japan. These short-term SSEs are often accompanied by non-volcanic or deep low-frequency tremors.
In the Tokai region, the previous long-term SSE occurred from 2000 to 2005, the longest SSE ever found. Ozawa and Yarai (2014) suggested the possible next SSE started to occur near the previous occurrence location in the beginning of 2013. Therefore, in this study, we analyzed the GPS data in the Tokai region to estimate the temporal evolution of the current event. The data for the period from 1 January 2008 and 30 April 2015 was used. The GIPSY-OASIS II software was used for estimating daily coordinates of the 226 GPS stations from the GEONET in the Tokai district. Then, the coordinate time series were fitted with linear trend and seasonal variations for the period before the 11 March 2011 Tohoku-oki earthquake (Mw9.0). The obtained linear trend was extrapolated to the end of data, 30 April 2015, and was subtracted from the original coordinate time series.
Then, the effects of the post-seismic deformation due to the Tohoku-oki earthquake were removed by fitting the data from 11 March 2011 to the end of the data with simple mathematical functions, not considering physical processes of the post-seismic crustal deformations. We employed a logarithmic function and a logarithmic plus exponential function to model the post-seismic deformation and found that the latter fits the data significantly better. We thus used the logarithmic plus exponential function to model and remove the post-seismic deformation.
After removing the post-seismic effects by the above pre-processing, we applied the time-dependent inversion method to the data to obtain the spatio-temporal evolution of slip beneath the Tokai region. For this purpose, we used a modified Network Inversion Filter (NIF) (Fukuda et al., 2008), which is a modification of the original NIF (Segall and Matthews, 1997). The original NIF assumes a constant hyperparameter for the temporal smoothing of slip rate and thus results in oversmoothing of slip rate. The modified NIF assumes a time variable hyperparameter, so that changes in slip rate are effectively extracted from GPS time series.
The results suggest that six short term SSEs were embedded in the slow and steady long-term SSE during the time interval from the beginning of 2013 to the end of April 2015. We investigated the detected short term SSEs in more detail. The results shows: first, rapid SSEs occurred from October to December 2013 and from August to October 2014 which were accompanied by low frequency tremors. Then, a rapid SSE occurred from the beginning of January to February 2014around the Ise Bay. This SSE was also accompanied by low frequency tremors. Finally, another SSE was found in April 2015 and this SSE was also accompanied by low frequency tremors.
The results indicate that the maximum slip for the long term SSE from 1 January 2013 to 30 April 2015, was estimated to be about 6 cm and the large slip was located in nearly the same area as or slightly to the south of the previous event. This long term SSE is still continuing at the end of April 2015.

