Extended Abstract of PhD Thesis

Activities of short-term slow slip events clarified by a newly developed systematic detection method using decadal GNSS data in the Nankai, Alaska, and Japan subduction zones

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1. Introduction

Slow slip events (SSEs) are an aseismic transient fault slip phenomenon observed by geodetic measurements including the Global Navigation Satellite System (GNSS). They are important for understanding the stress state and physical properties of faults. SSEs are categorized into two types depending on their duration: long-term SSEs (L-SSEs) lasting several months to several years and short-term SSEs (S-SSEs) continuing several days to several weeks. The synchronization between S-SSEs and tectonic tremors, namely, episodic tremor and slip (ETS), has been reported in several regions. Today, SSEs have been discovered in subduction zones and large active faults worldwide, and their source parameters, including magnitude, duration, and source depth, vary in regions.

The purpose of this thesis is to reveal the common and regional characteristics of S-SSEs and their causes. We chose southwest Japan, southcentral Alaska, and northeast Japan because of the long history of continuous GNSS observations and numerous studies on interplate slip phenomena including megathrust earthquakes. We improved a systematic detection method proposed by Okada et al. (2022) and applied it to decadal GNSS data in each region. In addition, we estimated slip models of L-SSEs in southcentral Alaska and the average fault models of offshore S-SSEs synchronizing with very-low-frequency earthquakes (VLFEs) to compare with the detected S-SSEs.

2. Data and methodology

Chapter 2 describes the data and methods for preprocessing GNSS data, S-SSE detection, estimation of S-SSEs' average properties, slip distribution of L-SSEs, and timeseries stacking referring to VLFEs. The improved S-SSE systematic detection method can be briefly summarized below.

The detection method is separated into three parts. The first part is the extraction of candidate events of S-SSEs. We applied the Geodetic Matched Filter (GMF) method (Rousset et al., 2017) to daily GNSS positions. The GMF is a template-matching technique considering the spatial extent of SSE signals. The second part of the detection method is the categorization of the candidates into S-SSEs. In this part, we firstly estimated a rectangular fault model and duration of candidates. Then, the candidates with characteristics like interplate slip are extracted and are recognized as S-SSEs based on the estimation results of the fault model and duration. The final part of the method is the uncertainty estimation of S-SSEs' duration using a bootstrap method.

3. Systematic detection of S-SSEs in southwest Japan

The activity of S-SSEs and L-SSEs in the Nankai subduction zone in southwest Japan is the best studied in the world. S-SSEs are zonally distributed from Kyushu to Tokai regions, and most of them are ETS-type S-SSEs. We investigated the relationship between S-SSEs and L-SSEs, and the S-SSEs synchronizing with VLFEs in southern Kyushu by applying the systematic detection method to decades-long GNSS data.

We detected 299 S-SSEs from July 1996 to January 2023. The number of events and the spatial pattern of the events are roughly consistent with those of Okada et al. (2022). We interpreted that most of the deep S-SSEs in Kyushu are an acceleration phase of L-SSEs because of the spatiotemporal coincidence between S-SSEs and L-SSEs. On the other hand, the occurrence rate and average slip of S-SSEs in western Shikoku significantly increase during the period of the Bungo Channel L-SSEs. We clarified that the increase in the regional moment rate of S-SSEs during the Bungo Channel L-SSEs (Nishimura et al., 2013) is caused by the increases in the number of S-SSEs (Hirose & Obara, 2005) and in the slip of each event.

The January 2010 S-SSE was detected by the systematic detection in southern Kyushu and temporally synchronized with VLFEs in Hyuga-nada. However, their fault plane does not overlap with the VLFEs' source area. We applied the timeseries stacking method referring to VLFE activities to GNSS data around Kyushu and estimated the average fault model to investigate S-SSEs' source location in more detail. The average fault model spatially overlaps with the source area of the VLFEs in Hyuga-nada. The stacking analysis indicates that ETS-type S-SSEs recurrently occur in Hyuga-nada. However, the average model is separately located further offshore than the 2010 S-SSE. The location difference can be caused by a low spatial resolving power of GNSS data and variation among individual events.

4. Systematic detection of S-SSEs in southcentral Alaska

The Pacific plate and Yakutat microplate subduct beneath the North America plate in southcentral Alaska. Although L-SSEs and tectonic tremors have been reported, only several S-SSEs have been identified as distinctive phenomena. We applied the systematic detection method and found 76 S-SSEs from July 2007 to January 2023. Most of the detected S-SSEs are located in the down-dip extension of the 1964 M 9.2 Alaska earthquake and in the region where the Yakutat microplate subducts. We interpreted that the microplate facilitates the S-SSE genesis in southcentral Alaska, similar to the tremor genesis (Wech, 2016). In addition, S-SSEs northeast of Cook Inlet are separately distributed in two clusters.

We compared the detected S-SSEs with the slip distribution of L-SSEs estimated in this study. S-SSEs are activated during the L-SSE periods in Upper and Lower Cook Inlets. On closer look, the activation is found in the eastern S-SSE cluster during the 2009-2013 Upper Cook Inlet L-SSEs, while there is no significant change of S-SSE activity in the western cluster. We speculated that the difference in the S-SSE activity among these clusters indicates the difference in the stress rate induced by the L-SSE in each cluster.

5. Systematic detection of S-SSEs in northeast Japan

In the Tohoku and Hokkaido districts, northeast Japan, the Pacific plate subducts beneath the Okhotsk plate, while the subducting plate is located beneath the Philippine Sea plate in the Kanto district. Although several studies have reported S-SSEs using GNSS and offshore geodetic measurements (Ito et al., 2013; Nishimura, 2021), the S-SSE activity in the entire subduction zones in northeast Japan is still unclear. Therefore, we investigated the S-SSEs using systematic detection and timeseries stacking methods.

We found 70 S-SSEs in northeast Japan via the systematic detection method. The S-SSEs were mainly located beneath and offshore Kanto, but dozens of the detected events were found in the Tohoku and Hokkaido districts. Although some were interpreted to be falsely recognized earthquake-related displacements as SSEs, we also found several probable SSEs in the Tohoku and Hokkaido districts, including an ETS-type SSE in Tokachi-Oki. The spatial variation of deep S-SSE distribution along trenches probably correlates with a difference in the overriding plates.

The timeseries stacking using VLFE bursts in Tokachi-Oki clarified the coherent seaward displacements around the Cape Erimo. The estimated source area of the Tokachi-Oki S-SSEs overlaps with that of tremors and VLFEs, consistent with the result of the systematic detection. The S-SSEs were located in the up-dip extension of the 2003 Tokachi-Oki earthquake. In addition, they coincide with the afterslip area of the 2003 earthquake.

6. General discussions and overall conclusions

Finally, we discuss the S-SSE activities in the above three analysis regions using the catalogs developed in Chapters 3-5. Our systematic detection highlights several common features and regional characteristics of S-SSEs. The spatial variation of S-SSE distribution along a trench relates to the difference in subducting or overriding plates. Most of the detected S-SSEs are located in the region where the Yakutat microplate subducts in southcentral Alaska. On the other hand, the difference in the overriding plates relates to the distribution of deep S-SSEs in northeast Japan. The activation of the detected S-SSEs during L-SSEs is also observed in southwest Japan and southcentral Alaska. However, the activation also has a regional difference, even in the S-SSEs distant less than 100 km, as suggested northeast of Cook Inlet. Comparison between SSEs and afterslip in three regions indicates that their source areas spatially overlap. The overlap suggests the complex behavior of interplate slip through an interseismic to a postseismic period.

Citation for published works

1. Development of a detection method for short-term slow slip events using GNSS data and its application to the Nankai subduction zone. *Earth Planets Space* **74**, 18. doi:10.1186/s40623-022-01576-8 (Published in January 24, 2022)

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2. Systematic detection of short-term slow slip events in southcentral Alaska. *Geophysical Research Letters* **50**, e2023GL104901. doi:10.1029/2023GL104901R (Published in September 7, 2023)

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