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COMMENTARY

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Key Points:

- Innovative transient slip detection methods like GriD-SSE enable to detect events with reduced signal-to-noise ratio
- Takagi et al. (2019) detected 24 long-lasting slow slip events with durations longer than 100 days in the Nankai subduction zone
- Long-lasting slow slip events lateral segmentation could be controlled by the stress shadows of seismic asperities

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Months-Long Subduction Slow Slip Events Avoid the Stress Shadows of Seismic Asperities

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Abstract With precise geodetic measurements, slow transient fault slip events with durations from days to years have been documented at subduction zones for two decades. Long-lasting transient events with durations longer than 100 days occur at the downdip edge of seismogenic zones. With such long durations, only a few events have been documented so far. Takagi et al. (2019, https://doi.org/10.1029/2018JB016738) propose a new methodology to detect these events and successfully apply it to the Nankai subduction zone in which they characterize 24 events, including 11 new detections. Combined with other observations from around the Pacific rim, they suggest that the lateral segmentation of long-lasting slow slip events is controlled by the location of seismic asperities associated with their stress shadows.

Since their discovery in the late 1990s (Dragert et al., 2001; Hirose et al., 1999), many slow slip events (SSEs) have been observed at subduction zones (Bürgmann, 2018; Schwartz & Rokosky, 2007), including deep and shallow events (Wallace et al., 2016), on opposite edges of the seismogenic megathrust. Like earthquakes, SSEs participate to release part of the stress built up by the convergence of the two plates. A distinction between short-lasting (days to weeks long) and long-lasting (months to years long) lasting SSEs has been made in the Nankai subduction zone where an along-dip spatial segmentation is observed (Obara et al., 2004). Short-lasting events are localized deeper, associated with a tectonic tremor strip at ~30-km depth, while long-lasting SSEs are localized between the short ones and the seismogenic zone (Obara & Kato, 2016). Long-lasting SSEs (longer than 100 days) are also observed in Mexico, New Zealand, and Alaska subduction zones, with different types of associations between short- and long-lasting events. In Mexico, long-lasting SSEs are observed both in the Guerrero and Oaxaca regions (Graham et al., 2016; Radiguet et al., 2012). Guerrero SSEs present a similar along-dip segmentation as the one documented in Nankai, with short events associated with tremors localized just below the longer ones (Frank et al., 2015; Rousset et al., 2017). Long-lasting SSEs in New Zealand are occurring in the southern section of the subduction below Manawatu and Kapiti, where the locked-to-creeping transition is located at ~30-km depth, while short events are occurring to the northeast, where the transition zone is much shallower at ~10-km depth (Wallace & Beavan, 2010). In Alaska, only three to four occurrences of years-long SSEs (2 and 5 years long) have been documented below the central and upper Cook inlets (Fu & Freymueller, 2013; Ohta et al., 2006). Since long-lasting SSEs are localized in close proximity to seismogenic zones and could produce stress perturbations into the seismogenic zones, it is of primary importance to better document them. Possible triggering has been suggested for two recent M_w 7.3 and 7.4 earthquakes in Mexico where these earthquakes nucleated during the occurrence of a nearby long SSE (Graham et al., 2014; Radiguet et al., 2016). The detection of a larger number of events will permit to perform robust statistics in order to see if global scaling laws hold for these events. And with such long durations, further detailed studies of their rupture, including both geodetic and seismic tremor observations, should shed light on the underlying physics.

Writing in *Journal of Geophysical Research*, Takagi et al. (2019) present a new method to catalog long-lasting SSEs and apply it to the western Nankai subduction zone. The method is based on a large library of synthetic events that the authors compare with moving windows of GPS time series. In order to detect and locate the events, they maximize the variance reduction between a large range of possible synthetics events and the GPS time series over subsets of GPS stations. An adaptive scheme optimizes the location, duration, fault size, and moment estimations for all detected events. The main advantage of this method, similar to the geodetic matched filter (Rousset et al., 2017), is that it extracts information from the whole GPS network to detect events, accounting for correct directions and relative amplitudes of the displacement, while most classical methods independently consider transient signals at single stations. Such an approach enables

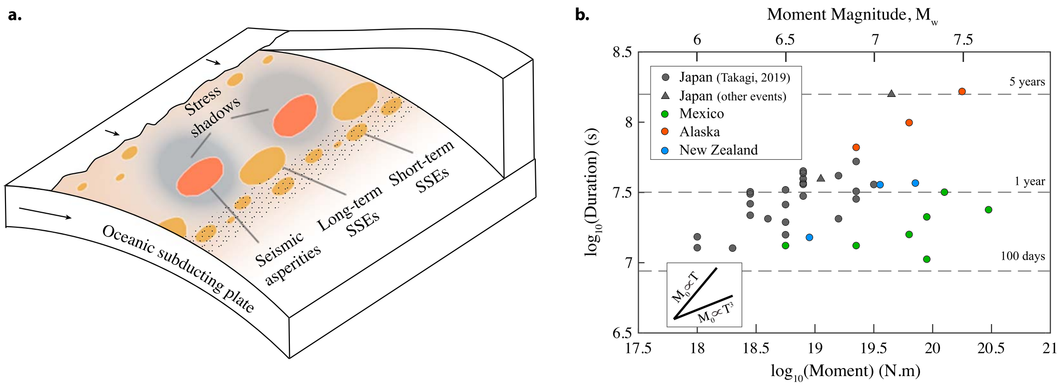

Figure 1. (a) Takagi et al. (2019) propose that the lateral segmentation of long-lasting slow slip events is controlled by the location of seismic asperities. In this schematic, seismic asperities are represented in red, with their stress shadows in gray and transient aseismic asperities in brown. The black dots symbolize tectonic tremors. (b) Moments versus durations for a compilation of slow slip events longer than 100 days documented in Japan (Kobayashi, 2014; Suito & Ozawa, 2009; Takagi et al., 2019), Mexico (Graham et al., 2016), Alaska (Fu & Freymueller, 2013; Ohta et al., 2006; Wei et al., 2012), and New Zealand (Wallace & Beavan, 2010) subduction zones. The earthquake scaling law ($M_0 \propto T^3$) and the scaling law suggested for slow earthquakes by Ide et al. (2007) ($M_0 \propto T$) are shown for comparison.

Takagi et al. (2019) to semiautomatically detect lower magnitude events, down to M_w 6.0 in the case of the Nankai subduction zone.

Applying this methodology to the western Nankai subduction zone, the authors characterized 24 SSEs with durations from 150 to 600 days, located at ~25-km depth, below the seismogenic zone. The deep tremor strip observed in most of the Nankai subduction zone associated with short SSEs stops at the western end of the Bungo channel, but long-lasting SSEs extend further to the southwest. By computing the cumulative slip released during these long transient SSEs between 1996 and 2017, they observe a clear lateral segmentation with two high-slip-amplitude areas separated by a gap, which coincides with the updip location of the 1968 Hyuga-nada M_w 7.5 earthquake. They also observe a smaller slip amplitude patch downdip of the 1946 Nankai M_w 8.3 Nankai earthquake where SSEs are less frequent. Extending the comparison between long-lasting SSEs and seismic asperities locations to the whole Nankai subduction zone, they argue for an anticorrelation, given that Kii and Tokai years-long SSEs are also located downdip from areas without strong seismic asperities and no clear evidence of long-lasting SSEs is observed below seismic asperities.

The proposed mechanism by Takagi et al. (2019) to explain this anticorrelation considers the stress shadows of the seismic asperities. Stress shadows lead to reduced interseismic slip rates around the periphery and especially updip of locked subduction zone asperities (Almeida et al., 2018; Bürgmann et al., 2005; Hetland & Simons, 2010). While being more prominent updip of the asperities, they also increase the interseismic slip deficit at their downdip edges (Figure 1a). With an effective high interseismic slip deficit due to stress shadows, areas below seismic asperities would indeed be less likely to produce long-lasting SSEs than areas at the same depths with no slip deficit, which could either creep steadily or produce transient SSEs. A more physics-based model of this effect would enable quantifying how deep these shadows extend at long-lasting SSE depths and what the remaining slip is that can be accommodated by aseismic slip.

Comparing long-lasting SSEs and seismic asperities at other subduction zones, this anticorrelation seems also particularly striking in the Mexico subduction zone, where both Guerrero and Oaxaca SSEs are occurring below areas of low coupling, devoid of large earthquakes (Graham et al., 2016; Radiguet et al., 2012). The anticorrelation is however less clear in Alaska and New Zealand, where more observations are needed and other effects might come into play to explain the location of long-lasting SSEs. In Alaska, even though the two SSE locations seem to be located in downdip areas where the great 1964 M_w 9.2 earthquake produced lower slip amplitudes (Holdahl & Sauber, 1994), the rupture being mainly offshore, the resolution on lateral slip amplitude variations remains quite poor. Also, lateral variations in slip deficit mapped from GPS interseismic velocities does not present clear lateral segmentation associated with the SSEs locations (Li et al., 2016). In New Zealand, lateral variations of interseismic coupling are strong, and the 2-year-long SSEs are located at downdip and along-strike transitions from locked to creeping (Wallace & Beavan, 2010), which could coincide with seismic asperity barriers. However, since the locked asperity last ruptured ~500 years ago (Clark et al., 2015), the precise relationships between the SSE regions and seismic rupture are not yet well constrained.

In order to better understand the physics behind these long-lasting SSEs, their location, and source parameters, further work is needed. While comparing durations and moments of SSEs longer than 100 days around the Pacific rim (Figure 1b), they appear to systematically have longer durations for higher moments at single subduction zones. However, no clear scaling seems to emerge globally. For example, a long-lasting SSE in Mexico and Alaska can have the same moment, but the Alaska one lasted 10 times longer. And a 3-month SSE in Mexico and Japan can have the same durations, but the moment of the Mexican one is 2 orders of magnitude higher than the Japanese one. In order to understand these discrepancies, numerical models accounting for local subduction geometric and rheological effects are needed, as well as more studies on the dynamic of the ruptures during these notably long transient slip instabilities. The geometry of subduction zones might play a role (Li & Liu, 2016), in particular, the low dip angles at locations of long-lasting SSEs in Mexico and Alaska are anomalies that should be considered. Finally, since these events are particularly long, they are good candidates to better understand the rupture dynamics in details. While GPS time series analyzed alone tend to produce models with smooth slip rates during the total duration of long-lasting SSEs (Fu et al., 2015; Miyazaki et al., 2006; Radiguet et al., 2011), recent studies incorporating the information from tremor occurrences suggest that they are rather made of a succession of short-lasting slip pulses at tremor times, with much higher slip-rate variations (Frank et al., 2018; Rousset et al., 2018).

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