

The Role of Slow Slip in Earthquake Cycles: Insight from Aseismic Slip Phenomena in Taiwan

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During the past decades, the discoveries of slow slip in the forms of slow strain release that does not produce shaking have established the broad spectrum of fault dynamics. They occur slowly, over the several tens minutes to days, rather than the few tens of seconds for ordinary earthquakes. Slow slip can accommodate most of a fault's slip budget, with equivalent magnitudes up to 4-5 in Taiwan. There exists various types of aseismic deformation that may alter the strain accumulation budget on the fault. The most profound feature of aseismic slip is their periodicity (e.g., Behr & Burgmann, 2021; Beroza & Ide, 2011; Ikari et al., 2020; Kano et al., 2019; Obara et al., 2010; Ozawa et al., 2007; Uchida et al., 2016). With the quasiperiodic behavior of slow aseismic slip, a sudden change of recurrence interval can be easily identified that provides the important information of the variation in loading rate before or after large earthquakes (Chen et al., 2010; Wallace et al., 2012; Bouchon et al., 2013; Kato et al., 2012; Liu et al., 2015; Obara & Kato, 2016; Ozawa, 2014; Uchida and Burgmann, 2019). Recognizing aseismic slip episodes during earthquake cycle therefore, is critical for earthquake forecasting and hazard assessment.

The suture zone in Taiwan, resulting from an arc-continent collision due to convergence of Eurasian Plate (EP) and Philippine Sea Plate (PSP), are responsible for active seismicity and presenting significant seismic risk. The understanding of interplay between slow slip and regular large earthquake is essential for the process of earthquake nucleation as well as earthquake cycle. In this suture zone several types of aseismic slip phenomena have been observed including repeating earthquakes, earthquake swarms, and tectonic tremors, making it an ideal region to tackle the question of "How the occurrence of slow slip affects the earthquake cycle?"

In this study, we use the 2000-2024 updated catalogs of repeating earthquakes (Peng et al., 2024), earthquake swarms (Peng et al., 2021), and tectonic tremors (Ide and Chen, 2024) to identify the spatiotemporal characteristics of the aseismic and seismic slip in Taiwan and assess the potential impact of such slow slip on the seismic cycle. Through comprehensive collection of aseismic slip phenomena in Taiwan, we found that in space, the earthquake swarms in Taiwan are highly overlapped with repeating earthquakes especially the creeping segments with high creep rate (4-5 cm/yr) on the southern Longitudinal Valley fault and northern Central Range fault; Tectonic tremors rooted in the lower crust on the other hand, are clustered along the mountain belt that coincides with the termination of EP and PSP where the tectonic forcing allows the vertical mobility of metamorphic fluids to happen. In time, the tectonic tremors reveal annual cycles that are not strongly correlated with large earthquakes but associated with regular hydrological loadings; The aseismic slip episodes from repeating events and earthquake swarms, however, appear to accelerate before large earthquakes.

The most outstanding example occurred in the source area of the 2024 M7.3 Hualien event. As shown by the example in Figure 1, the elevated earthquakes swarms occurred since 2021 that coincided with increasing aseismic slip rate derived from repeaters. We demonstrate that the spatiotemporal characteristics of aseismic slip provides a valuable framework for understanding the long-term evolution of aseismic slip rate. The preslip and afterslip signals can be observed on the faults that creeps fast during seismic cycles.

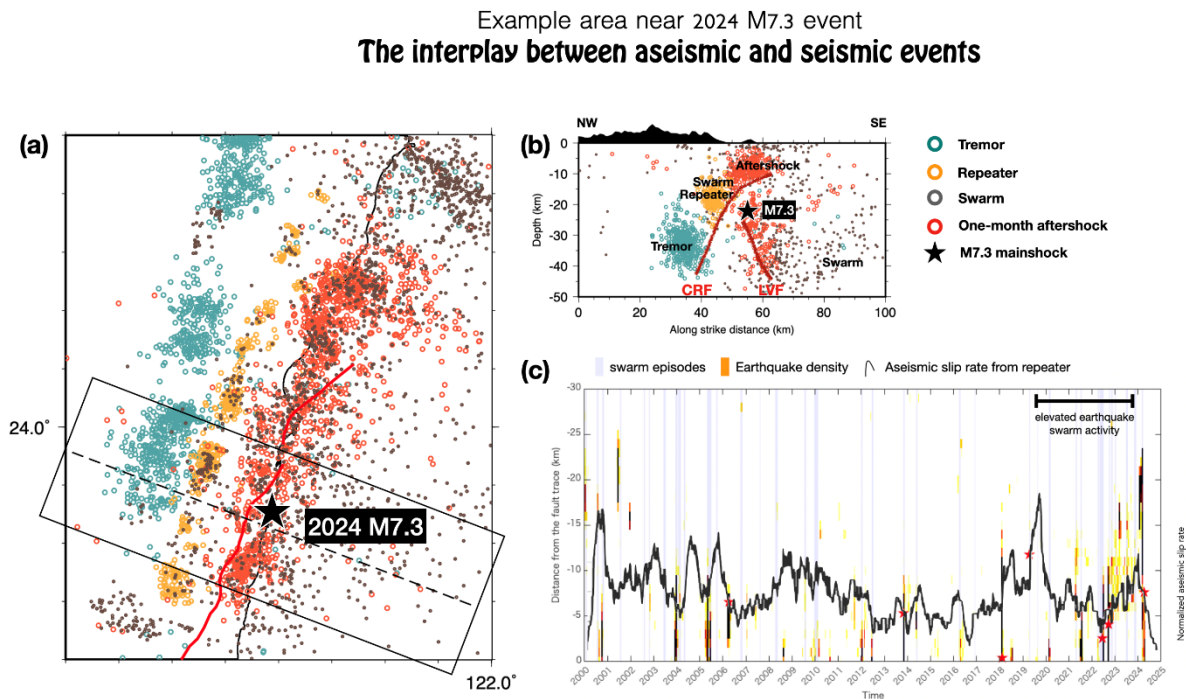
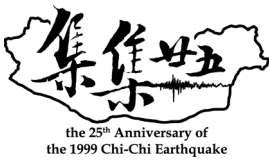


Figure 1. (a) Example area near the 2024 M7.3 Hualien earthquake showing the spatial closeness between the mainshock-aftershock sequence and slow slip driven phenomena (swarms, repeaters, and tectonic tremors). (b) Cross-section showing the alignment of tremors, repeaters, swarms, and part of the aftershocks on the west-dipping Central Range fault. (c) Long-term aseismic slip derived from repeaters (black curve) comparing with the high density of earthquake activities (yellow to dark red color) and timing of earthquake swarms (light purple lines).

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