P55

Detection of Repeating Earthquakes Offshore El Salvador in the Central America Subduction Zone and Implications for Plate Slip Behavior

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Understanding the slip behavior along subduction zone plate boundaries is essential for evaluating the potential for megathrust earthquakes. Off the coast of El Salvador along the Middle America subduction zone, a large interplate earthquake of M_w 7.3 occurred in 2012 (Ye et al., 2013). However, the detailed slip behavior of the plate boundary—including locked, steady slip, and slow slip regions—remains poorly understood. Clarifying these behaviors is crucial for assessing the risk of megathrust earthquakes and the associated tsunamis off the coast of El Salvador.

In this study, we conducted the first detection of small repeating earthquakes in the offshore El Salvador region. Small repeating earthquakes are caused by repeated ruptures of small locked areas on the plate interface and are known to serve as natural creep meters (Uchida, 2019; Uchida & Bürgmann, 2019). We first applied PhaseNet (Zhu & Beroza, 2019), incorporated in the SeisBench library (Woollam et al., 2022), to broadband waveform data from the El Salvador seismic network spanning from January 2014 to December 2024, to detect earthquakes.

As a result, we detected 2,150 earthquakes with magnitudes of M 3.5 or greater. We then calculated waveform cross-correlation (Igarashi et al., 2003) to identify repeating earthquakes among these events. Specifically, we used the vertical component of the waveform from the P-wave arrival to 3 seconds after the S-wave arrival. Events were identified as repeating earthquakes if the correlation coefficient exceeded 0.95 at two or more stations. For the waveform correlation calculation, a 2–8 Hz bandpass filter was applied to events with M 3.5 to M 4.5, and a 1–4 Hz filter to events with M 4.5. As a result, 298 events were classified into 89 repeating earthquake sequences, with up to 10 repeated events in a single sequence. These repeating earthquakes exhibited a distinctly bimodal distribution in the direction perpendicular to the trench axis. On the landward side, many sequences showed high repeat counts. We then estimated the slip per event using the circular crack model (Eshelby, 1957), assuming a stress drop of 10 MPa. The estimated slip rate for many sequences on the landward side was comparable to the relative plate motion rate. This suggests that, on the deeper portion of the plate boundary (i.e., landward), most of the relative plate motion is accommodated by steady slip.

In contrast, a clear gap in repeating earthquake activity was found on the shallower portion of the plate boundary (at depths of 15 to 30 km). Based on observations from the Japan Trench and the Nankai Trough subduction zones, where repeating earthquakes tend to be sparce within megathrust locked patches (Uchida et al., 2016; Uchida & Bürgmann, 2019), it is inferred that this region is highly locked and has the potential to generate megathrust earthquakes. In fact, the 2012 Mw 7.3 interplate earthquake ruptured the southeastern part of this region (Ye et al., 2013). In contrast, the northwestern part has not experienced an interplate earthquake larger than M 7 in the past 50 years, suggesting that slip deficit may be accumulating there.

Additionally, several earthquake swarms containing repeating earthquakes were detected in regions very close to the trench axis (i.e., at depths shallower than 15 km). In other subduction zones—such as the Japan Trench, Sagami Trough, and Hikurangi subduction zones—earthquake swarms containing repeating earthquakes have frequently been observed during slow slip events (e.g., Nishikawa et al., 2023). This suggests that slow slip events may be occurring in the offshore El Salvador region as well.

Our study provides important insights into the slip behavior of the plate boundary off El Salvador and contributes to the assessment of tsunami hazard in the region.