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Unravelling Physics of Massive Tsunami Generation Using In-Situ Ocean-Bottom Pressure Gauge Data

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Ocean-bottom observations are essential for studying earthquake and tsunami processes in the ocean. Traditionally ocean-bottom pressure gauges (PGs) were used to observe tsunamis, while recent studies have revealed that they capture geophysical phenomena across a wide period range from seconds to years. Utilizing this capability, I have analysed in-situ PG data, recorded inside the earthquake source region, to reveal the physics of massive tsunami generation. In this presentation, I introduce my recent works related to the analyses of the in-situ PG data, which provides important insights into earthquake and tsunami mechanics, particularly in the Tohoku subduction zone, in northeastern Japan.

First, I highlight advances in earthquake source modelling using dynamic pressure changes recorded by the in-situ PGs (Kubota et al. 2017; 2021). PGs can detect not only tsunamis ranging periods of ~10^2–10^3 s but also dynamic pressure changes caused by seismic waves, covering periods of 10^0~10^2 s (e.g. Filloux 1982). Applying solid-fluid coupled wave theory (e.g. Saito 2019), I developed a technique to simulate the dynamic pressure fluctuations and successfully modelled broadband in-situ PG data including both long-period tsunamis and short-period seismic components. This method integrates the spatial reliability and robustness of tsunami data with the temporal resolution of seismic data.

Next, I present a case study of the 2011 Tohoku earthquake using the in-situ PGs to explore the mechanics of its large near-trench slip (> 50 m) resulting in a devastating tsunami (Kubota et al. 2022). While the kinematics of this anomalous slip have been studied well, its driving force and underlying physics remain unresolved. Using the in-situ tsunami waveforms recorded by the PGs together with geodetic datasets, I reliably estimated the distributions of slip and shear stress release on the megathrust fault plane. The results showed the near-trench slip (> 50 m) occurred with minimal stress drop (< 3 MPa) at depths < 10 km, while large stress release (> 5 MPa) occurred deeper near the hypocenter ~15 km). This suggests the near-trench slip occurred without releasing the pre-accumulated shallow stress but was driven instead by strain energy releases in the deeper region under the free-surface effects near the trench. This implies that similar large shallow slips could occur in other subduction zones even without significant shallow strain energy accumulation but only with deeper stress release.

Seafloor pressure observations have significantly advanced tsunami propagation modelling and the evaluation of tsunami source kinematics. Integrating in-situ observations with solid-fluid coupled wave theory refines kinematic modelling and enhances understanding of tsunami generation mechanism and underlying physics. Unravelling the physics of massive tsunami generation is crucial for assessing a wide range of potential future tsunami sources, including megathrust events, tsunami earthquakes, and sequential earthquake rupture scenarios.