Dynamics of foreshocks and pre-slip during the nucleation of laboratory earthquakes

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Over the past decades, an increasing number of seismological observations and improvement in data quality have allowed to better detect foreshock sequences prior to earthquakes. However, due to strong spatial and temporal variations of foreshock occurrence, their underlying physical processes and their links to earthquake nucleation are still under debate. Here we address these issues by looking at precursory acoustic activity during laboratory earthquakes (stick-slip instabilities).

Here, laboratory earthquake experiments were performed on saw-cut Indian metagabbro under upper crustal stress conditions ranging from 30 to 60 MPa confining pressure. Using a high-frequency monitoring system and calibrated piezoelectric acoustic sensors we continuously record particle velocity field at 10 MHz sampling rate during the experiments. Based on a trigger logic we identify acoustic emissions (AE) within continuous data. From P-wave arrival-time data and from spectral analysis we are able to estimate the following seismological parameters for each AE: location, absolute magnitude, stress-drop and size.

First, we show that the source parameters of AE (Mw -9.0 to Mw -7.0) follow the same scaling relationship as natural earthquakes justifying the use of acoustic precursors as proxy to foreshocks. We observe that foreshock triggering is systematically related to aseismic slip and that the dynamics of foreshocks mirrors the acceleration of slip-rate preceding failure. Experimental scalings demonstrate that: i) the nucleation evolves from an aseismic process into a cascading one, and ii) the duration and magnitude of the pre-seismic moment correlates with the magnitude of the mainshock, at least at the scale of the laboratory. Finally, using Hertz contact theory, we find a scaling law between the seismic energy released by foreshocks, the fault roughness and the normal stress acting on the fault interface.