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Analog modelling of subduction megathrust earthquakes: challenges, applications and future directions

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Subduction megathrust earthquakes are among the most dangerous geo-hazards. They derive from the stress build up caused by plates convergence and friction acting along the megathrust. Such stress is episodically released by ruptures that may span several hundreds of km, resulting in magnitude 8 or larger earthquakes. The short instrumental record and the multi-scale, multi-parameter influence complicate our understanding of the origin and loci where those earthquakes may occur in the future. These two types of complications are perfect targets for analog modeling. This technique in fact allows reproducing a given geologic process in space- and time continuum and in convenient temporal- and spatial scales. Moreover, analog models allow testing various parameters influence simply changing the boundary conditions. Analog models, about ten years ago, were adopted to investigate long-term processes such as subduction or mountain building, except only few examples. Using them for studying earthquakes represented a challenging research subject for various reasons, including the research of a new analog material, the development of the experimental setup, scaling, monitoring and processing of tens of GB of data. Modelling subduction earthquakes started with studying the rheology of gelatins with the goal of finding the right type, concentration, temperature and aging allowing properly scaling the rheological properties of the upper plate. The second step has been a focus on friction of the gel-on-sandpaper system using simple spring-block experiments. By varying systematically the loading rate, normal load and roughness, the physical conditions leading to velocity weakening frictional behavior (a key ingredient for modeling the spontaneous nucleation and propagation of analog earthquakes) have been identified. These two preliminary studies allowed to develop a new apparatus featuring a flat subducting plate driven at constant velocity and underthrusting a viscoelastic gelatin wedge analog of the overriding plate. In the model, stress build up is episodically released via spontaneous ruptures that propagate along the analog megathrust. The rupture width-slip proportionality and seismic moment-duration scaling have been investigated at the beginning, aiming to test dynamic similarities with natural earthquakes. Then, these models have been used to investigate the role of subduction velocity and width of the seismogenic zone in tuning megathrust seismicity. For the sake of simplicity, these initial models were quasi-3D. Moving to a 3D model configuration allowed investigating the asperities synchronization process. Similarly to a domino cascade, asperities synchronization is thought to be responsible for large lateral rupture propagation and, in turn, the origin of mega-earthquakes. Particular emphasis has been put on how the size and distance of asperities influence the synchronization. At present, these models are used for investigating how the interseismic deformation can be used for predicting the earthquake slip pattern. The long timeseries of dense geodetic-like information are capable to feed computer-science algorithms capable of learning from the large amount of data. I envision that applying machine learning for analyzing these model will help to shed new light for predicting the pattern of future earthquakes.