Data and scripts from Neighbouring segments control on earthquake recurrence patterns: Insights from scaled seismotectonic models (https://doi.org/10.5880/fidgeo.2025.046)

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1. Licence

2. Citation

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3. Data description

We provide particle image correlation data from the 16 laboratory experiments with Foamquake seismotectonic model simulating analog megathrust seismic cycles and supporting scripts. To monitor analog seismic cycles, we use a high-resolution camera taking images at 50 frames per second as an analog of a geodetic satellite. We are using a trench orthogonal surface velocity time series extracted from the central points located above the seismic asperities using Particle Image Velocimetry (PIV) method.

3.1. Experimental setup and experimental configurations:

We use Foamquake, a scaled seismotectonic analog model that simulates megathrust seismic cycles (Mastella et al., 2022). Foamquake is designed to scale ~500 km in the along-strike direction of the analog subduction (i.e., length scaling factor L* is $2.9*10^{-6}$, i.e., 1 cm in the model corresponds to 3.5 km in nature, Mastella et al., 2022). The setup consists of a Plexiglas box containing a wedge made of foam rubber (representing the overriding plate) which is underthrusted by a flat layer of granular material that is driven by a motor-powered belt (representing the subducting plate) at a constant velocity of 0.01 cm/s. The time scaling factor for the coseismic phase is defined as 1 s in the model corresponds to 590 s in nature, and for the interseismic phase the scaling factor is defined as 1 s in the model corresponds to 100 years in nature (Mastella et al., 2022). The granular material layer between the foam wedge and conveyor belt has patches of rice as velocity-weakening seismogenic segments (representing seismic asperities: in this work, we use the words segment and asperity as synonyms) surrounded by velocity-neutral quartz sand (Mastella et al., 2021). Asperities (areas with high interseismic coupling and coseismic slip, Aki, 1979) and barriers (areas with relatively weaker interseismic coupling and less coseismic slip, Lay and Kanamori, 1981) are important features of subduction megathrust segmentation.

We test single and double asperity configurations along strike. The single asperity experiments have an asperity size of 20 x 20 cm in trench parallel and orthogonal directions. In double asperity configurations, we keep constant their downdip extent and depth range according to the worldwide average for seismogenic zones (Heuret et al., 2011). The symmetric configuration consists of two asperities of equal size (20 x 30 cm), and was developed by Mastella et al. (2022). The asymmetric configuration is characterised by a small (20 x 30 cm) next to a larger asperity (52.5 x 30 cm) along strike. The spacing between asperities is 40 cm along strike for both configurations. An extra normal load (normal stress, σ_n) of rice of 10, 40, 70, 100, or 130 Pa is applied from the model surface in order to tune the strength of asperities. For the symmetric and asymmetric configurations, we performed four experiments, varying the σ_n on one of the two asperities while keeping σ_n = 40 Pa on the other. For the asymmetric configuration, we varied σ_n on the long or short asperity while keeping σ_n = 40 Pa on the neighbor asperity.

3.2. Data processing and Metrics:

To monitor analog seismic cycles, we use a high-resolution camera taking images at 50 frames per second as an analog of a geodetic satellite. The wedge surface is marked with black dots (geodetic network) to track the deformation of the model. We sequentially process images with the PIV method using the MatPIV package (Sveen, 2004) to obtain the surface velocity field. The two-dimensional surface velocity field is extracted by cross-correlating between consecutive images sampled into 16x25 interrogation windows for single asperity and double asymmetric asperity experiments and 23x31 for double symmetric asperity experiments, which together simulate a spatially dense continuous geodetic network. Interrogation windows are spaced every 5.8 cm for the 16x25 matrices and 4.7 cm for the 23x31 matrices in both the normal and trench-parallel directions of the model. In the data we share we only use matrix data along the trench along the central reference point.

Each experiment starts with a ~1-minute elastic loading phase of the wedge, after which the model starts to exhibit stick-slip behaviour. Slip instabilities that nucleate and propagate at the plate interface occur spontaneously.

During the stick-phases (i.e., analog of interseismic periods), we observe velocities generally toward the backstop, which indicates a mechanical coupling of the analog subduction interface. Slip phases exhibit reversed velocities directed toward the trench and are evident as velocity peaks in the PIV time series. Threshold determination to distinguish modeled seismic events from aseismic motion is an unavoidable feature of laboratory time series. In our experiments, we set a threshold of 0.1 cm/s. We interpret velocities above this threshold as belonging to analog earthquakes. We also consider sensitivity (i.e., minimal elapsed time between subsequent events) of 0.2 s. Sensitivity allows associating to unique rupture events that are closer than 0.2 s. Setup preparation, threshold and sensitivity setting can affect the strength of asperities and rupture proportions, however the general trends due to differences in normal loading are clearly evident. We then define an event by setting a velocity threshold based on a reference time series extracted from the center points of the asperity surface projections.

The PIV method allows us to retrieve the displacement field, from which we calculate recurrence time (Rt) and its coefficient of variation (CoV). Rt and CoV are used to describe the earthquake recurrence behaviour (e.g., Kempf & Moernaut, 2021, Griffin, 2021). CoV is defined as a ratio of the standard deviation to the mean value of Rt. Random Poisson behaviour of the system is characterised by CoV = 1, aperiodic behaviour by CoV > 0.5, quasi-periodic behaviour by CoV < 0.5, and periodic behaviour by CoV = 0 (Kagan & Jackson, 1991). The fault area along strike is partitioned into parts based on the matrices obtained from the PIV process. Rt and CoV are calculated for the center surface projections of asperities and areas between them over time.

4. File description

4.1. PIV datasets and supporting scripts

We provide surface velocities from the laboratory experiments. We are using a trench orthogonal velocity time series extracted from the central (reference) point located above the seismic asperities. PIV data is located in the 'data' subfolder. For each experiment we provide the following data:

.csv files named events_<>.csv (for example, events_130Pa_single.csv) store a 2-D array of thresholded events (in our experiments we set a threshold of 0.1 cm/s).

Table 1. Description of *.csv files named events_<>.csv*

Experiment type	Shape	Description
Double-symmetric asperities	(31, 4500)	**Rows (31)** – trench-orthogonal surface-velocity components (cm/s) at 31 positions along the trench, along the center point of asperity. **Columns (4500)** – 4 500 camera frames = 90 s of experimental time
Single asperity and Double-asymmetric asperities	(25, 4500)	**Rows (25)** – trench-orthogonal surface-velocity components (cm/s) at 31 positions along the trench, along the center point of asperity. **Columns (4500)** – 4 500 camera frames = 90 s of experimental time

In the article we analyse only the final 60 s, i.e. frames 1 500 – 4 499 (coded as matrix_masked[:, 1500:]).csv files named events_<>.csv (for example, events_130Pa_single.csv) store a 2-D array events above the threshold.

Name '_130Pa_single' give an information of the experiment – which configuration: single, double symmetric or asymmetric is used, about extra load on asperity (e.g., 130Pa_single – 130 Pa is applied above single asperity; 40_130Pa_long_fixed – 40 Pa above long asperity, 130 Pa above the short asperity and so on); and which asperity is fixed with the load of 40 Pa (40_130Pa_long_fixed – 40 Pa above long asperity fixed in all set of experiments, and so on).

.csv files with the name **cv_matrix_** (e.g., cv_matrix_130Pa_single.csv) contain a matrix with the sizes of (100, 25) and (100, 31), where the CoV value calculated for 100 threshold values along strike through the center of asperity (asperities), CoV is a dimensionless value. Dimensions 25 and 31 refer to different experiments as described above.

With the data above we are using scripts in the subfolder 'scripts' **figure3.py, figureS3.py, figureS4.py, figureS5.py, figureS6.py.**

We are also using scripts with the names:

time_series_cumsums_for_40_40Pa_long_fixed.py,
time_series_cumsums_for_40_40Pa_short_fixed.py,
time_series_cumsums_for_40_130Pa_long_fixed.py,
time_series_cumsums_for_40_130Pa_short_fixed.py

for plotting time series and cumulative sum plots for four double asymmetric asperities experiments to give a general idea of what the data look like (Figure 1). Data like that:
'40_40Pa_long_fixed_center_of_long_asp.csv' are presended as 1-D array (numpy.ndarray) referring to the reference point (center point of asperity) velocity time series in **cm/s** over time.

Scripts have been tested with Windows and Linux machines with Python 3.11.5 version using Spyder IDE. It is important to define the working directory when plotting all the figures.

Description of the variables we are using in our work and scripts:

Recurrence time Rt: time between events.

Coefficient of variance CoV: CoV is defined as a ratio of the standard deviation to the mean value of Rt.

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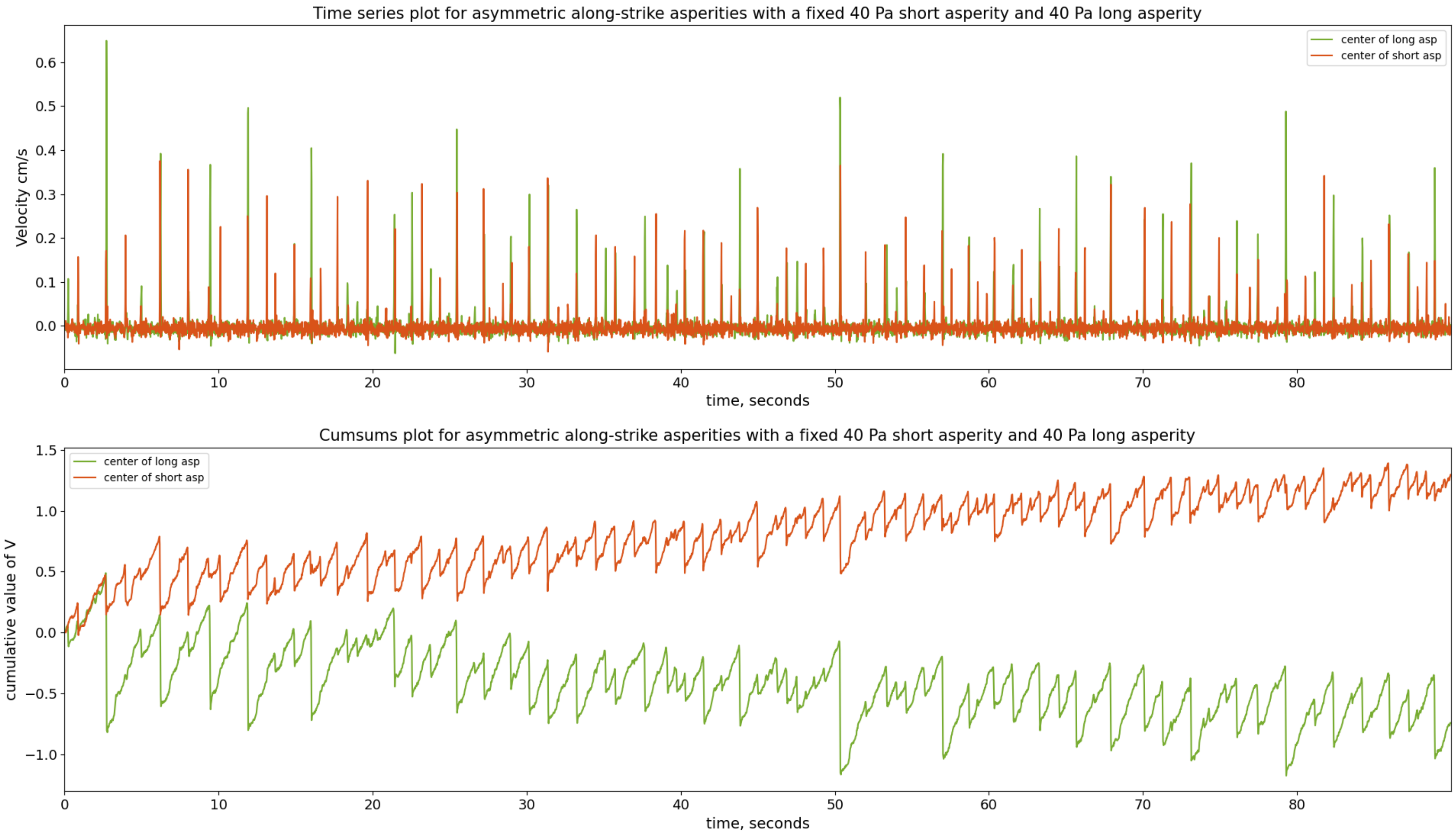

Figure 1. Time series plot for the double asymmetric asperities configurations with 40 Pa fixed short asperity and 40 Pa long asperity, time-series extracted from two points on the model surface located above the centre of the long asperity (green; 40 Pa load) and short asperity (orange; 40 Pa load). And tick-slips dynamics represented by two velocity time-series extracted from two points on the model surface located above the centre of the long asperity (green; 40 Pa load) and short asperity (orange; 40 Pa load)