EGU2020-12056
https://doi.org/10.5194/egusphere-egu2020-12056
EGU General Assembly 2020

Quantifying preparation process of large earthquakes: Damage localization and coalescent dynamics

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We attempt to track and quantify preparation processes leading to large earthquakes using two complementary approaches. (a) Localization of brittle deformation manifested by evolving fractional volume with seismic activity, and (b) Coalescence of earthquakes into clusters. We analyze seismicity catalogs from Southern California (SoCal), Parkfield section of the San Andreas Fault (SAF), and region around the 1999 Izmit and Duzce earthquakes in Turkey.

Localization of deformation is estimated using the Receiver Operating Characteristic (ROC) approach. Specifically, we consider temporal evolution of the fractional volume $0 \leq V(q) \leq 1$ occupied by the fraction $0 \leq q \leq 1$ of active voxels with mainshocks. We also consider the localization of the spatial intensity of mainshocks within a sliding time window with respect to the time-averaged distribution, quantified by Gini coefficient G. The significance of the results is assessed using reshuffled catalogs. Analysis within the rupture zones of large earthquakes indicate decrease of V(q) and increase of G (increased localization) prior to the Landers (1992, M7.3), El Mayor-Cucapah (2010, M7.2), Ridgecrest (2019, M7.1), and Duzce (1999, M7.2) mainshocks. We also observe ongoing damage production by the background seismicity around these rupture zones several years before their occurrences. In contrast, we observe increase of V(q) and decrease of G prior to the Parkfield (2004, M6.0) mainshock in the creeping section of the SAF. Next, we examine the quasi-linear region in the Eastern part of Southern California around the Imperial fault, Brawley seismic zone, southern SAF and Eastern California Shear Zone. We document four cycles of background localization, measures by V(q) and G, well aligned in time with the largest events in the region: Landers, Hector Mine, El Mayor-Cucapah, and Ridgecrest. The coalescence process is represented by a time-oriented graph that connects each earthquake in the examined catalog to all earlier earthquakes at the earthquake nearest-neighbor proximity below a specified threshold. We examine the size of the clusters that correspond to low thresholds, and hence represent active clustering episodes. We document increase of the average cluster size prior to the Landers, El Mayor-Cucapah, Ridgecrest and Duzce mainshocks, and decrease of the average cluster size prior to the Parkfield mainshock.

The results of our complementary localization and coalescent analyses consistently indicate progressive localization of damage prior to the largest earthquakes on non-creeping faults and de-localization on the creeping Parkfield section of SAF. These findings are consistent with analysis of

acoustic emission data. The study is a step towards developing methodology for analyzing the dynamics of seismicity in relation to preparation processes of large earthquakes, which is robust to spatio-temporal fluctuations associated with aftershock sequences, data incompleteness and common catalog errors.