2020 SCEC Project Report * Project 20065

Space-time variations of background seismicity in southern California

1. PROJECT SUMMARY

The project aimed at developing methodology and analyzing the dynamics of seismicity in relation to preparation processes of large earthquakes and long-term evolution of seismic patterns. The project particularly focused on examining a special form of non-stationary behavior – evolving localization of background seismicity. The project resulted in refined techniques for analyzing localization of seismicity with a focus on the complex plate-boundary region in Southern California (SoCal) and Alaska. The research on localization of background seismicity combined current efforts in earthquake declustering, coalescent representation of seismicity, and a novel technique for quantifying time-dependent spatial localization of earthquakes. The research used the current updated version of the *Hauksson et al.* [2012] relocated catalog, and other catalogs for California and Alaska. The project trained graduate students and facilitate cross-disciplinary collaboration between UNR and USC.

2. PROJECT RESULTS

Summary of results: The project developed a methodology for robust quantification of space-time localization of earthquakes – one of the principal mechanisms of generation of large earthquakes [***Kato and Ben-Zion*, 2021**]. The methodology has been applied to (i) Quantifying regional localization of raw and background seismicity in Southern California, and (ii) Quantifying time-dependent localization associated with preparation processes of large earthquakes in Southern California (**Fig. 1**) and Alaska [***Ben-Zion and Zaliapin*, 2020**]. The project is using the nearest-neighbor declustering of ***Zaliapin and Ben-Zion* [2020]** as an essential part of its methodology. The project contributed to the general theory of random self-similar trees [***Kovchegov and Zaliapin*, 2020; *Kovchegov et al.*, 2021**] that are used to represent earthquake flow and are the essential element of nearest-neighbor cluster analyses (including earthquake declustering). The project also examined environmental earthquake triggering in Southern California [***Zhou et al.*, 2020**]

Project outcomes: The project results are presented in a peer-reviewed publications and multiple conference presentations (see a list below).

2.1 Localization and coalescence of seismicity before large earthquakes [*Ben-Zion and Zaliapin*, GJI, 2020; *Kato and Ben-Zion*, 2021]

We examine localization processes of low magnitude seismicity in relation to the occurrence of large earthquakes using three complementary analyses: (i) estimated production of rock damage by background events, (ii) evolving occupied fractional area of background seismicity, and (iii) progressive coalescence of individual earthquakes into clusters. The different techniques provide information on different time scales and on the spatial extent of weakened damaged regions. Techniques (i) and (ii) employ declustered catalogs to avoid the occasional strong fluctuations associated with aftershock sequences, while technique (iii) examines developing clusters in entire catalog data. We analyze primarily earthquakes around large faults that are locked in the interseismic periods, and examine also as a contrasting example seismicity from the creeping Parkfield section of the San Andreas fault. Results of analysis (i) show that the $M > 7$ Landers 1992, Hector Mine 1999, El Mayor-Cucapah 2010 and Ridgecrest 2019 mainshocks in Southern and Baja California were preceded in the previous decades by generation of rock damage around the eventual rupture zones (see **Fig. 1**). Analysis (ii) reveals localization (reduced fractional area) 2-3 yr before these mainshocks and before the $M > 7$ Düzce 1999 earthquake in Turkey. Results with technique (iii) indicate that individual events tend to coalesce rapidly to clusters in the final 1-2 yr before the mainshocks. Corresponding analyses of data from the Parkfield region show opposite delocalization patterns and decreasing clustering before the 2004 M6 earthquake. Continuing studies with these techniques, combined with analysis of geodetic data and insights from laboratory experiments and model simulations, might improve the ability to track preparation processes leading to large earthquakes.

2.2 Environmental Triggering of Seismicity in California [*Zhou et al.,* AGU, 2020]

Exploring the potential triggering of earthquakes by environmental forcing terms, such as water mass loading and surface temperature changes, contributes to the understanding of crustal mechanics and dynamics of seismicity. The various geological and geomorphic settings in California provide the opportunity to perform a comparative study of nontectonic modulation of seismicity under different conditions. In this study we use 14 years of water storage changes estimated from global positioning system (GPS) vertical elastic loading deformation time series, water levels in aquifers, and a declustered version of the ANSS Comprehensive Earthquake Catalog (ComCat) to analyze correlations between background seismicity rate variations and different possible forcing terms in various sub regions in California. The results show a variety of correlations that suggest different possible dominant forcing terms in different locations. Significant detected correlations will be modeled with poroelastic and thermoelastic frameworks in a future study.

2.3 Earthquake declustering perspective [*Zaliapin and Ben-Zion,* 2021]

Declustering earthquake catalogs has been used in analyses of seismicity for over 50 yrs, but basic questions remain on the proper outcome and quality metrics of declustering. We address these questions from the perspective of modern high-quality data sets and problems related to dynamics of seismicity. Earthquakes in instrumental catalogs are concentrated heavily within a very small fraction of the examined space-time volume that is highly amplified by activity associated with the largest recorded events. The events that are included in the short-duration instrumental catalogs are not representative of the overall long-term behavior of seismicity in tectonically active regions. Declustering earthquake catalogs may help to clarify the long-term regional earthquake behavior and increase signal-to-noise ratio of effects that are subtler than aftershocks and other strong signatures of clustering. At present, declustering remains an exploratory tool, rather than a rigorous optimization problem, and specific applications should depend on the data and problem at hand.

Project publications:

Published papers:

1. Ben-Zion, Y. and I. Zaliapin (2020) Localization and coalescence of seismicity before large earthquakes. *Geophys. J. Intl.* 223(1), 561-583. https://doi.org/10.1093/gji/ggaa315
2. Kato, A. and Y. Ben-Zion (2021) The generation of large earthquakes. *Nature Reviews Earth & Environment*, 2, 26–39, https://doi.org/10.1038/s43017-020-00108-w
3. Kovchegov, Y. and I. Zaliapin (2020) Random Self-Similar Trees: A Mathematical Theory of Horton Laws. *Probability Surveys*, 17, 1–213. https://doi.org/10.1214/19-PS331
4. Zaliapin, I. and Ben-Zion, Y. (2020) Earthquake declustering using the nearest-neighbor approach in space-time-magnitude domain. *Journal of Geophysical Research: Solid Earth*, *125*(4), e2018JB017120.

Papers in review:

5. Ben-Zion, Y. and I. Zaliapin (2021) A perspective on earthquake declustering. In review.
6. Kovchegov, Y., I. Zaliapin, and E. Foufoula-Georgiou (2021) Random Self-similar Trees with Applications to Geophysics. In review.

Conference abstracts/proceedings:

1. Ben-Zion, Y. and I. Zaliapin (2020) Localization and coalescence of seismicity before large earthquakes. Abstract T004-0006 presented at *2020 Fall Meeting of AGU, Online, Dec. 1-17.*
2. Zhou, B., I. Zaliapin, C. Johnson, Y. Fu, K. Chanard and Y. Ben-Zion (2020) Environmental Triggering of Seismicity in California. Abstract S038-0008 presented at *2020 Fall Meeting of AGU, Online, Dec. 1-17.*
3. Zaliapin, I., K. Henricksen, and K. Zuev (2020) Hyperbolic geometry of earthquake networks. Virtual workshop "*Micromechanics, Statistics and Hazards of Mechanical Failure*" at The Centre de Recerca Matemàtica, Spain, Oct. 19-22. http://fail.crm.cat/
4. Zaliapin, I. and Ben-Zion, Y. (2020) Quantifying preparation process of large earthquakes: Damage localization and coalescent dynamics. Virtual workshop "*Micromechanics, Statistics and Hazards of Mechanical Failure*" at The Centre de Recerca Matemàtica, Spain, Oct. 19-22. http://fail.crm.cat/
5. Zaliapin, I. (2020) Localization and coalescence of seismicity before large earthquakes in California. Plenary talk at 2020 SCEC Annual Meeting, Sep 14-17, 2020. Contribution #10227.
6. Zhou, B., Zaliapin, I., Johnson, C. W., Fu, Y., Chanard, K., & Ben-Zion, Y. (2020). Environmental triggering of seismicity in California. Poster #10208 Presented at 2020 SCEC Annual Meeting, Sep 14-17, 2020.

7. Zaliapin, I. and Ben-Zion, Y. (2020) Quantifying preparation process of large earthquakes: Damage localization and coalescent dynamics, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-12056, https://doi.org/10.5194/egusphere-egu2020-12056 (Solicited talk)
8. Zaliapin, I., Henricksen, K., and Zuev, K. (2020) Hyperbolic geometry of earthquake networks, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-12091, https://doi.org/10.5194/egusphere-egu2020-12091

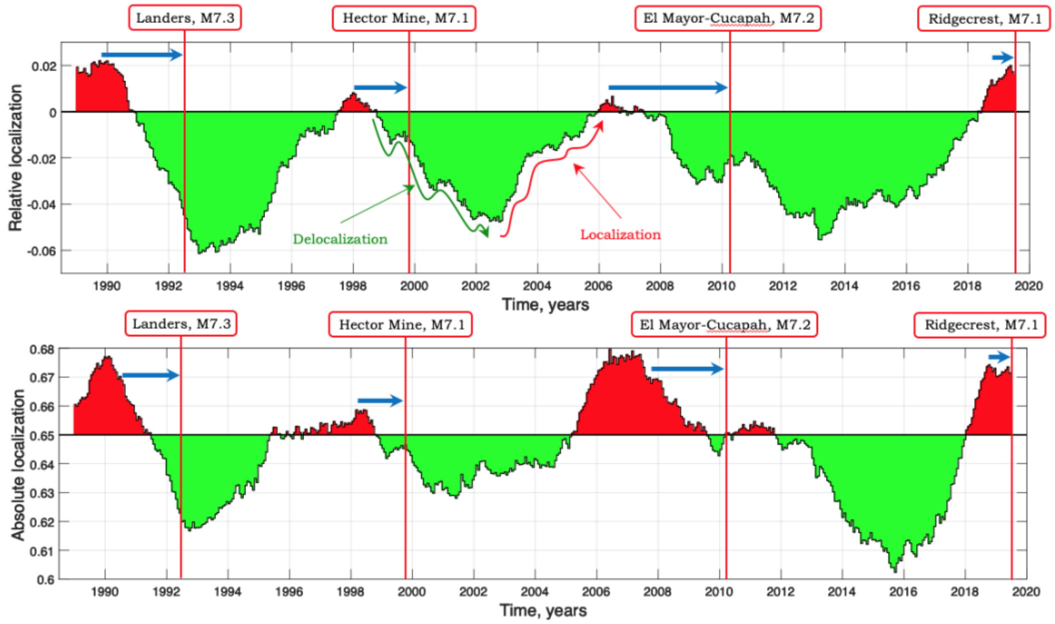

Figure 1: Localization of background seismicity in Southern California. (**Top**) Relative localization with respect to a previous time interval. Its positive values indicate that the current spatial background distribution is a localized version of the earlier one – it has the same support and co-located yet more prominent peaks. (**Bottom**) Absolute localization. Its higher values indicate stronger deviation from the uniform spatial measure, or spikiness. The localization is estimated using square cells with linear size $\Delta\phi = 0.4°$, windows w_1 = 3yr (current distribution), w_2 = 5yr (earlier distribution), and threshold P_0 = 10 (minimal number of events in a cell). The four large earthquakes with $M > 7$ are marked by red vertical lines. Every target event occurred within 4 years after the localization peak. The blue arrows indicate the lead time from localization peak to a large event.