2021 SCEC Project Report * Project 21041
Localization of seismicity prior to large earthquakes in California

1. PROJECT SUMMARY

The project continues the PI efforts in tracking generation of earthquake-induced rock damage and evolving localization and coalescence of background seismicity (projects #19063 and #20065). The proposed studies apply refined techniques for analyzing localization of seismicity to expanded region that includes southern California, northern California and Alaska, and will formulate general expectations of earthquake localization process in different seismicity settings. The project will also examine localization in AE data from rock fracture experiments. The research on localization of background seismicity combines current efforts in quantifying earthquake-induced rock damage, time-dependent spatial localization of earthquakes, and earthquake declustering. The research uses the current updated version of the *Hauksson et al.* [2012] and *Waldhauser and Schaff* [2008] relocated catalogs, and other catalogs for California and Alaska. The project trains graduate students and facilitate the cross-disciplinary collaboration between UNR and USC.

2. PROJECT RESULTS

Summary of results: The statistical methodology for tracking localization of earthquake-induced rock damage that has been initially developed for California seismicity has been scaled to examine events of higher (Alaska) and lower (AE experiments) energies. The new results with crustal Alaska seismicity and AE seismicity from a range of experiments by different groups are consistent with our earlier findings and show a systematic variability of localization in relation to preparation process of large events.

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

2.1 Localization of seismicity before large earthquakes in Alaska

Our 2020 SCEC project examined localization processes of low magnitude (M > 2) seismicity in relation to the occurrence of large earthquakes in California using evolving occupied fractional area of background seismicity. The results showed 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 and localization (reduced fractional area) of seismicity 2-3 yr before these mainshocks. Corresponding analyses of data from the Parkfield region showed opposite delocalization patterns and decreasing clustering before the 2004 M6 earthquake. The **current project** developed a scaled version of the localization procedure that has been applied to the crustal (depth < 70km) seismicity of Alaska. In this analysis, both the examined events and target events have larger magnitudes than those examined in California: we tracked localization of M > 4 events prior to M > 7.8 earthquakes (**Fig. 1**). We found three cycles of absolute and relative localization associated with five M7.8 events. The increases of localization coincide in time with three Gulf of Alaska targets (1987 M7.9, 1988 M7.8, and 2018 M7.9) and preceded by 2-3 years the 2002 Denali M7.9 and 2020 AK Peninsula M7.8 earthquakes. The detected cycles are robust with respect to the numerical parameters of the algorithm (time and space averaging).

2.2 Localization of damage prior to system-size event in rock fracture experiments

We applied the methodology for tracking localization to data from several rock fracture experiments. Specifically, we considered seven AE data sets from *Lockner et al*. (1992), *Goebel et al.* (2012), and *Stanchis* (2006). In one of the experiments, a saw cut (notch) was introduced to the sample prior to the experiment. The other six data sets correspond to fracturing an intact sample. All examined data sets show a single cycle of absolute and relative localization. In five experiments with an intact sample (**Fig. 2**), the absolute localization increases prior to the system-size event and remains high during the sample failure. This reflects concentration of AE events in a single location (which may migrate with time). The relative localization increases at the time of or slightly after the increase of absolute localization, reflecting increased concentration of events in a fixed (non-migrating) location around the impending system-size fracture. The relative localization then decreases prior to the failure reflecting concentration of events within a propagating fracture front. In a single experiment with a notch, we observed an inverted dynamic, with both absolute and relative localization decreasing prior and during the system-size fracture. This reflects high initial concentration of events around the artificial sample imperfection, and distribution of events to a broader area immediately prior and during the main failure. Finally, in an experiment with Westerly Granite (*Lockner et al.*, 1992), the localization cycle occurred after the system-size failure.

2.3 Earthquake declustering perspective [*Zaliapin and Ben-Zion*, SRL, 2022]

Clustering is a fundamental feature of earthquakes that impacts basic and applied analyses of seismicity. Events included in the existing short-duration instrumental catalogs are concentrated strongly within a very small fraction of the space–time volume, which is highly amplified by activity associated with the largest recorded events. The earthquakes that are included in instrumental catalogs are unlikely to be fully representative of the long-term behavior of regional seismicity. We illustrate this and other aspects of space–time earthquake clustering, and propose a quantitative clustering measure based on the receiver operating characteristic diagram. The proposed approach allows eliminating effects of marginal space and time inhomogeneities related to the geometry of the fault network and regionwide changes in earthquake rates, and quantifying coupled space–time variations that include aftershocks, swarms, and other forms of clusters. The proposed measure is used to quantify and compare earthquake clustering in southern California, western United States, central and eastern United States, Alaska, Japan, and epidemic-type aftershock sequence model results. All examined cases show a high degree of coupled space–time clustering, with the marginal space clustering dominating the marginal time clustering. Declustering earthquake catalogs can help clarify long-term aspects of regional seismicity and increase the signal-to-noise ratio of effects that are subtler than the strong clustering signatures. We illustrate how the high coupled space–time clustering can be decreased or removed using a data-adaptive parsimonious nearest-neighbor declustering approach, and emphasize basic unresolved issues on the proper outcome and quality metrics of declustering. At present, declustering remains an exploratory tool, rather than a rigorous optimization problem, and selecting an appropriate declustering method should depend on the data and problem at hand.

Project publications:

Papers:

1. Zaliapin, I. and Y. Ben-Zion (2022) Perspectives on clustering and declustering of earthquakes. *Seismological Research Letters* (2022) 93 (1): 386–401 https://doi.org/10.1785/0220210127
2. Ross Z., Y. Ben-Zion and I. Zaliapin (2021) Geometrical properties of seismicity in California, *Geophys. J. Intl.* (in revision)

Conference abstracts/proceedings:

1. Zaliapin, I. and Y. Ben-Zion (2021) Earthquake clustering and localization of seismicity before large earthquakes. Abstract T15A-0163 presented at *2021 Fall Meeting of AGU, Dec. 13-17* (online)
2. Zaliapin, I. and Y. Ben-Zion (2021) Earthquake clustering and localization of seismicity before large events. Poster #251 Presented at 2021 SCEC Annual Meeting, Sep 12-17, 2021 (online).
3. Zaliapin, I. and Y. Ben-Zion (2021) Localization of seismicity prior to large earthquakes. In *EGU General Assembly Conference Abstracts*, pp. EGU21-14086 (online).
4. Zaliapin, I. and Y. Ben-Zion (2021) Localization of Seismicity Prior to Large Earthquakes. *A paper presented at the 2021 Annual Meeting of the Seismological Society of America 19-23 April, 2021* (online).

References:

1. Goebel, T. H. W., Becker, T. W., Schorlemmer, D., Stanchits, S., Sammis, C., Rybacki, E., & Dresen, G. (2012). Identifying fault heterogeneity through mapping spatial anomalies in acoustic emission statistics. *Journal of Geophysical Research: Solid Earth*, *117*(B3), B03310.
2. Stanchits, S., Vinciguerra, S. & Dresen, G. (2006) Ultrasonic velocities, acoustic emission characteristics and crack damage of basalt and granite. *Pure Appl. Geophys.,* 163, 975–994.
3. Lockner, D. A., J. D. Byerlee, V. Kuksenko, A. Ponomarev, and A. Sidorin (1992), Observations of quasistatic fault growth from acoustic emissions, in *Fault Mechanics and Transport Properties of Rocks*, edited by B. Evans and T.-f. Wong, pp. 3-31, Academic Press, London.

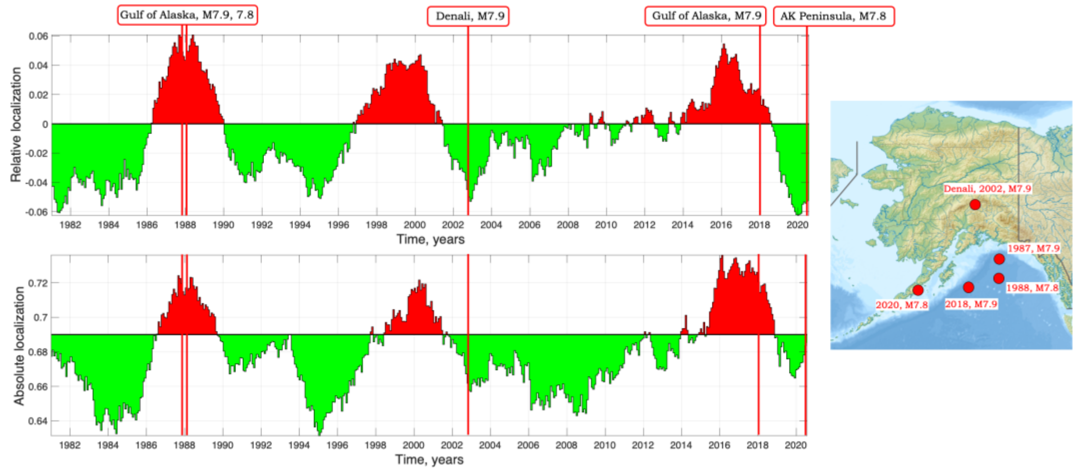

Figure 1: Localization of background seismicity in Alaska. (**Top**) Relative localization with respect to a previous time interval. Its positive values indicate that the current spatial background distribution is a localized version of the earlier one – it has the same support and co-located yet more 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 $w_1 = 3$yr (current distribution), $w_2 = 5$yr (earlier distribution), and threshold $P_0 = 10$ (minimal number of events in a cell). The five large earthquakes with $M > 7.8$ are marked by red vertical lines. Every target event occurred within 3 years after the localization peak.

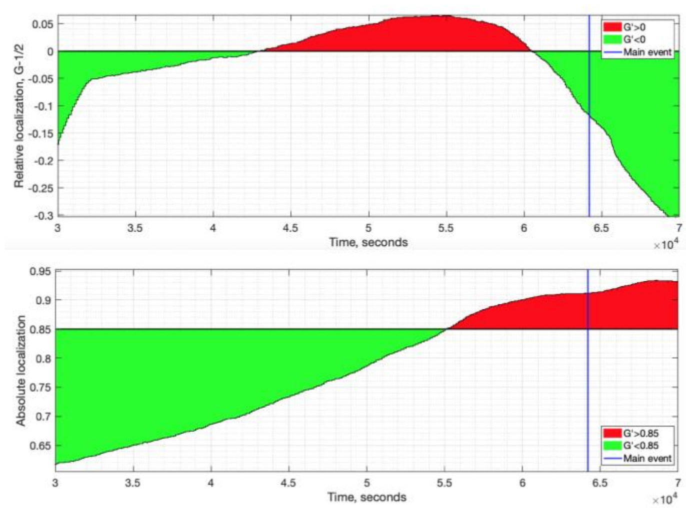

Figure 2: Localization of AE events in Berea Sandstone fracture experiment of Lockner et al. (1992). (**Top**) Relative localization with respect to a previous time interval. (**Bottom**) Absolute localization. Its higher values indicate stronger deviation from the uniform spatial measure, or spikiness. System-size fracture moment is marked by blue vertical line.