Correlations of Deep Tectonic Tremor and Crustal Earthquake Activity

Implications for their use in forecasting frameworks and for understanding the segmentation of tremor intermittence

Bibliography

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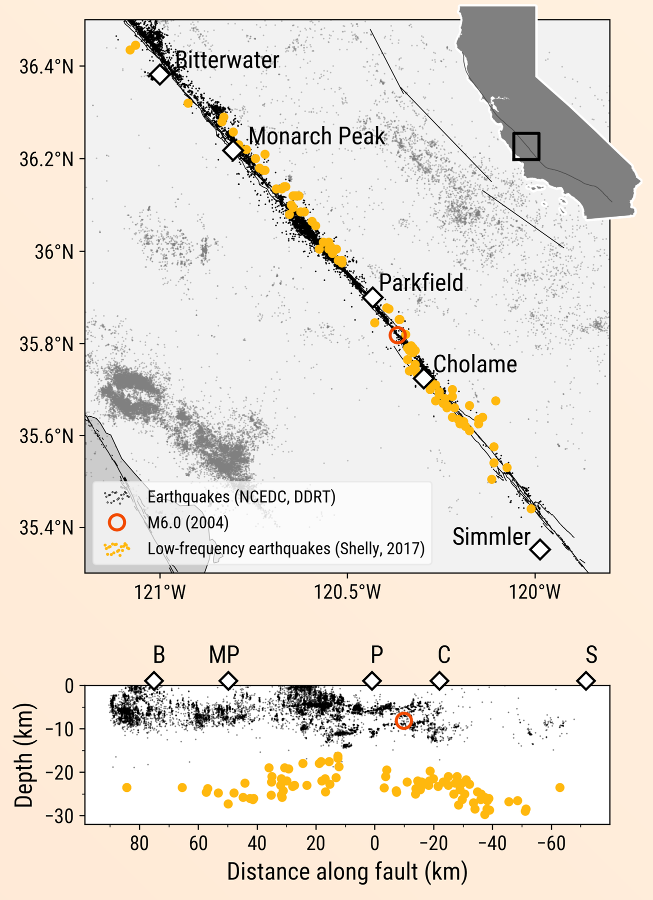
In short

Regular and "slow" earthquakes interact through static and dynamic stress transfers. Using the seismic signature of slow earthquakes — tremor and low-frequency earthquakes (LFEs) — ***we attempt to detect the influence of smaller scale slow earthquakes on the local rate of regular crustal seismicity.***

In Parkfield, ***we could not find any significant seismicity change after high LFE activity****, thwarting our hopes of using them in forecasting frameworks. However,* ***we detect triggering of LFE activity by local, small earthquakes.***

In different tremor zones across the world, a faint correlation between nearby earthquake activity and loss of spatio-temporal synchronization of tremor activity leads us to believe that ***the spatial segmentation of tremor intermittence could be partly dictated by perturbations due to the activity of local small earthquakes*** *— through dynamic triggering.*

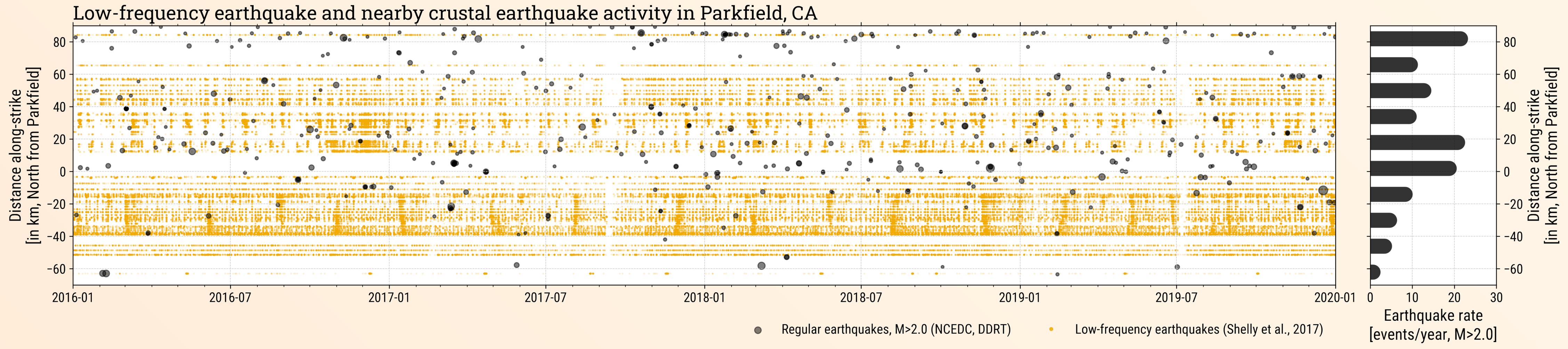
A. Correlations of earthquake and LFE activity in Parkfield, CA



Known correlations between regular and slow earthquakes (seen through tremor/LFEs) in Parkfield:

- **Static triggering** by local, large earthquakes (San Simeon 2003 M6.5, Parkfield 2004 M6.0, *Shelly & Johnson, 2011*)
- **Dynamic triggering** from +/- distant, large earthquakes (Denali M7.9 2002, South Napa M6.0 2014, Alum Rock M5.3 2007… *Shelly et al., 2011*)

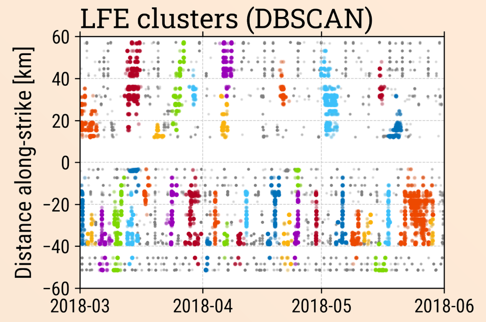
No known systematic pattern of tremor activity preceding a change in crustal earthquake activity.

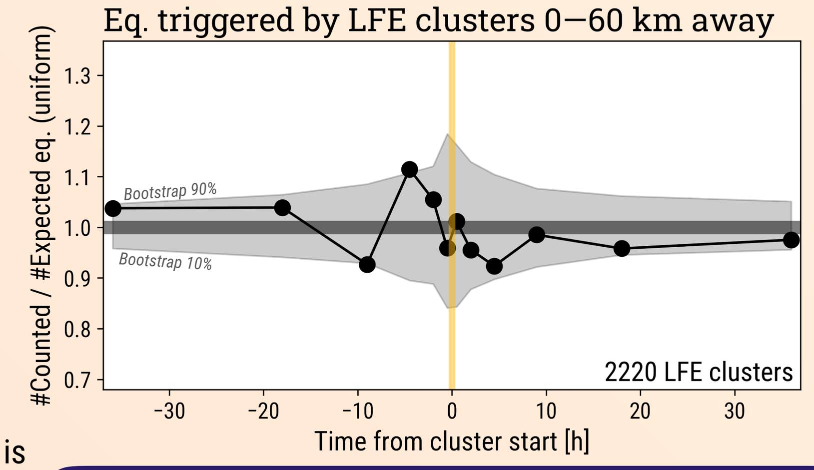


A.1. Do slow earthquakes trigger earthquakes?

We count the number of earthquakes before and after LFE clusters, in a spatial region around them.

Clusters are detected using a clustering algorithm.





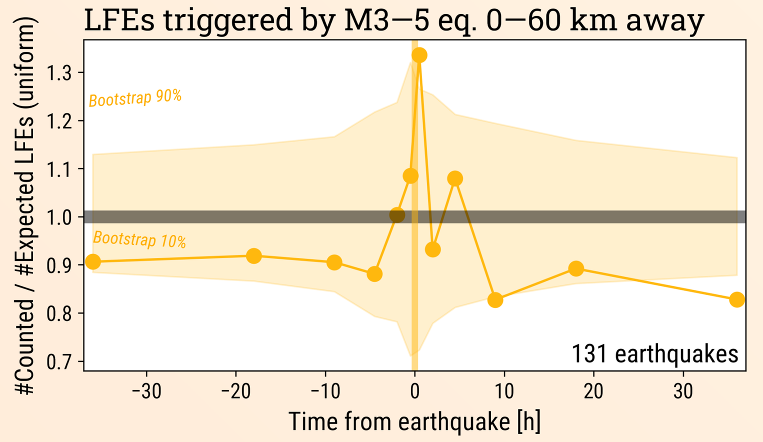
The number of counted earthquakes is compared to what is expected if the seismicity rate was uniform in time (spatial distribution preserved).

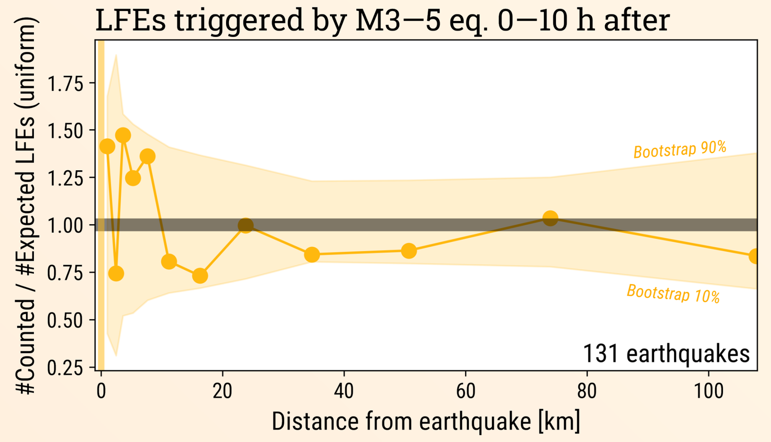
No significant change of earthquake activity after LFE activity

To compute the confidence interval, we resample (x1,000) the occurence times of the clusters and perform the same analysis.

A.2. Do local, small earthquakes trigger LFEs?

As in A.1, we count the number of LFEs around earthquakes, in time and space, between 2006 and 2023.





LFE activity marginally increases after and around small earthquakes

Conclusion of A.:

Using the available catalogs in Parkfield, CA, we could not detect any influence of slow-earthquake activity on the crustal seismicity. Using LFE activity in deep-learning forecasting frameworks therefore seems fraught with unwanted bias during the learning phase — e.g. correlation of detection capacity between the catalogs.

B. Correlation of tremor segmentation and nearby earthquake activity

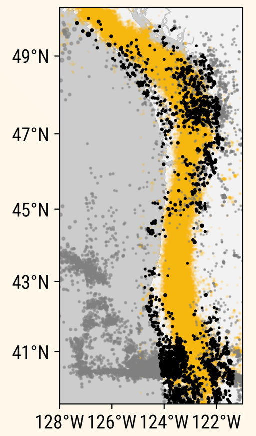
We have shown that the local influence of small earthquakes can trigger tremor activity. Here, we look for evidence that they could influence the large-scale recurrence patterns of tremor, and play a part in shaping its segmentation along-strike.

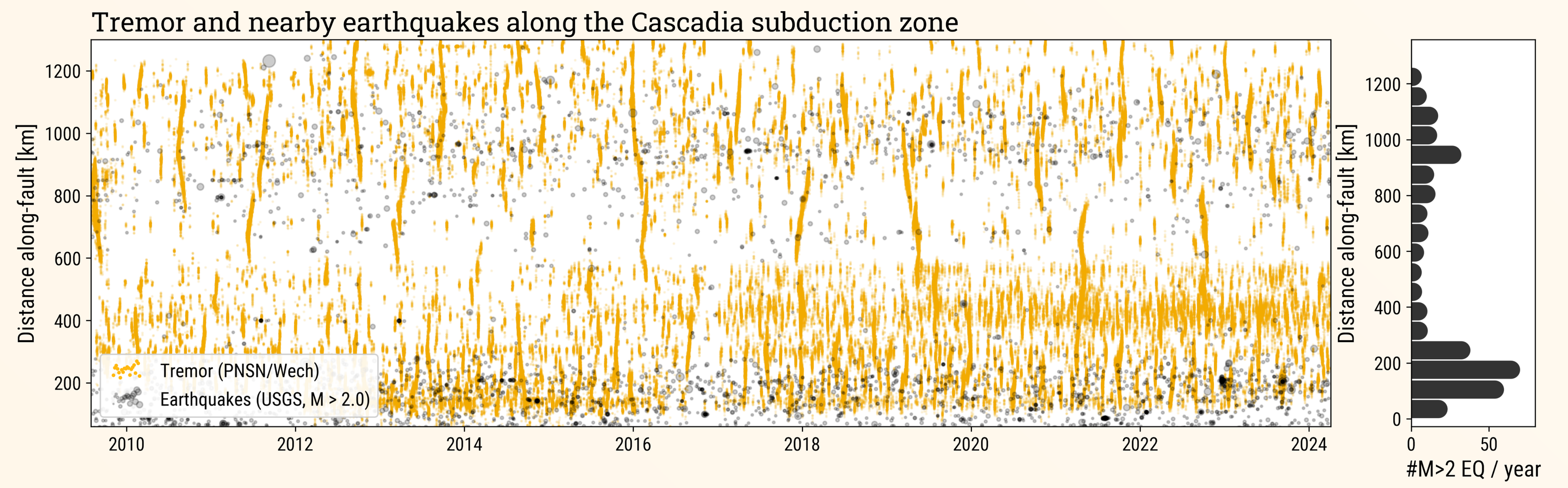
B.1. Tremor in Cascadia (USA, Canada)

The subduction can be divided in 3 segments, based on the intermittence behavior of episodic tremor and slip: the timescale of its recurrence, and its regularity.

Tremor segmentation has been linked to the geologic segmentation of the upper plate *(Brudzinski & Allen, 2007).* The resulting variations of frictional and hydraulic properties could explain the variety of tremor patterns *(Farge et al., 2023)*.

The intensity of earthquake activity near the tremor zone seems to loosely correlate with the organization of tremor activity *— its recurrence timescales and regularity.*





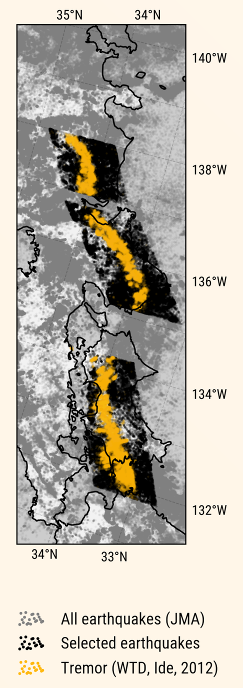
B.2. Tremor in Nankai (Japan)

The three tremor zones in Nankai all display complex segmentation.

The spatial variations of tremor activity in those zones loosely correlates with topographical features of the incoming plate *(Ide, 2010, Farge et al. 2023).* Variations in frictional and hydraulic properties induced by the large-scale roughness of the subduction interface could shape the tremor segmentation.

As in Cascadia, ***zones of low seismicity loosely correspond to spatially synchronized, very periodic tremor activity*** *(and slip),* ***while high seismicity correlates with less periodic, shorter-synchronization-length tremor activity*** *(especially in Kii and Shikoku.*

The local activity of small earthquakes could be an external perturbation to the internal dynamics of episodic tremor and slip, and partly explain the segmentation of its spatio-temporal synchronization.

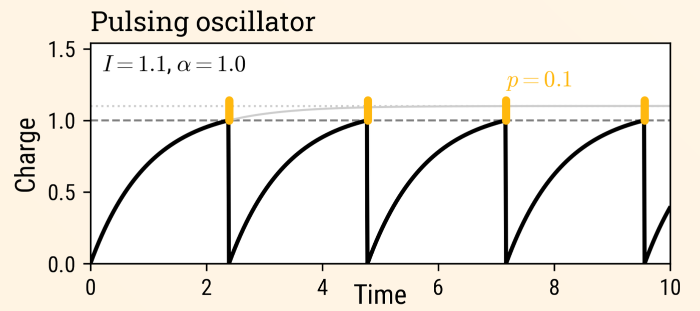


C. A model of perturbation-induced desynchronization of tremor activity

Tremor sources are modeled as pulse-coupled oscillators in a line. They charge (get stressed) following:

$$\dot{y}(t) = I - \alpha y(t)$$

When $y = 1$, the source fires a charge pulse p, communicated to its direct neighbors. ***Spatio-temporal synchronization emerges from this interaction.***



External simulation (simulated earthquakes) is imposed on the bottom and top thirds of the system, as random occurence of pulses of charge p.

Tremor segmentation can be simulated through local perturbation (earthquakes) to its internal synchronization processes (slip? fluid?)