Spatiotemporal Variation in Low Frequency Earthquake Recurrence on the San Andreas Fault

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1. Motivation and Objectives

▶ LFEs: low-frequency (1-10 Hz) earthquakes with small magnitudes.
▶ Occur adjacent to major faults in overlapping sequence forming persistent seismic tremors [4], associated with slow slip events in the phenomenon of episodic tremor and slip (e.g. [1],[2]).
▶ High occurrence rate and comprehensive detection of LFEs enables insights regarding more elusive earthquake processes along plate boundaries.
▶ We examine the recurrence patterns displayed by the 88 LFE families that are grouped at distinct generating locations adjacent to the San Andreas fault, and how these are affected by large earthquakes.
▶ We model activity migration between generating locations on the fault.

3. Hidden Markov Models

▶ Describe underlying geological mechanisms with discrete time Markov chain $\{Y_t : t = 1, 2, ...\}$, satisfying first-order dependence $\mathbb{P}(Y_t|Y_{t-1}, ..., Y_t) = \mathbb{P}(Y_t|Y_{t-1})$.
▶ Hidden states Y_t take values from $i = 1, ..., m$ (m state HMM).
▶ Time between LFE events $X_t(t = 1, 2, ...)$ depends only on current Y_t.

Observed LFE X_1 X_2 X_3 $\cdots$ X_t $\cdots$

Hidden Process Y_1 Y_2 Y_3 $\cdots$ Y_t $\cdots$
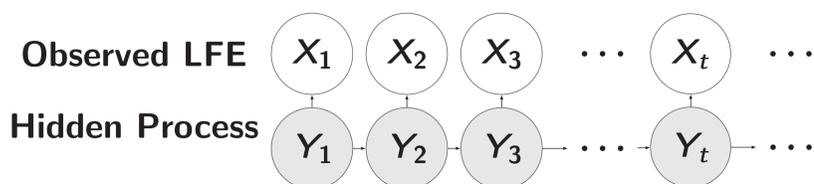
5. Recurrence Pattern of Continuous Events

▶ Progression - High transition to intermediate activity (states 2 and 3) and high transition to quiescence (state 6).
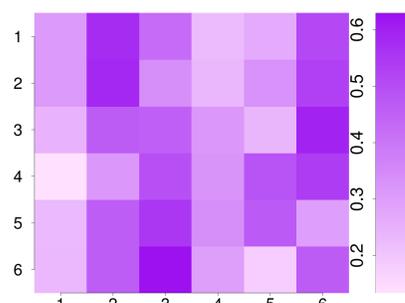▶ Relatively constant activity rates, less impacted by slip movement?
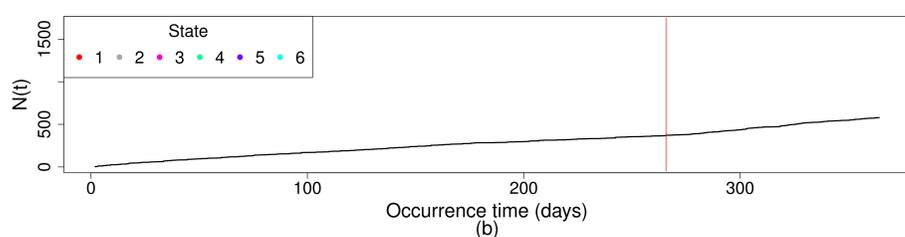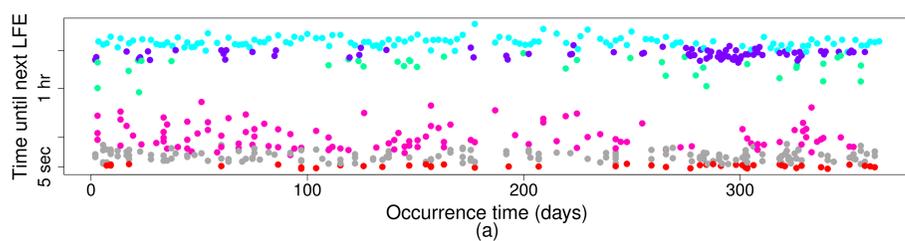


Figure 4:As for Figure 2.

Figure 5:As for Figure 3.

7. Conclusions

▶ Differences in recurrence behaviour between LFE locations provide insights regarding fault structure and the direction/propagation of slow slip.
▶ Clustering methods summarise patterns (more complex than linear transition) in the migration of activity between spatially distinct generating locations.

References

[1] G. Rogers and H. Dragert.*Science*, 300:1942–1943, 2003.

[2] K. Obara. *Journal of Geodynamics*, 52:229–248, 2011.

[3] D. R. Shelly. *Journal of Geophysical Research: Solid Earth*, 122:3739–3753, 2017.

[4] M. Supino, N. Poiata, G. Festa, J. P. Vilotte, C. Satriano, and K. Obara. *Scientific Reports*, 10(6523), 2020.

2. San Andreas LFE Data
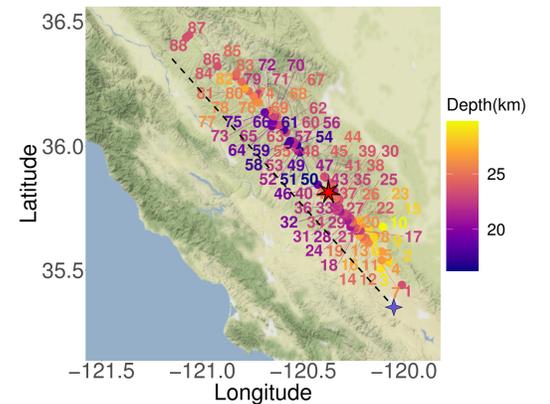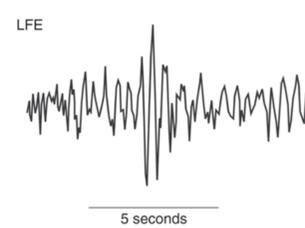
▶ Events recorded January 2004 to September 2016, assigned to most likely generating location [3].
▶ Model time between events (log secs).

Figure 1:Locations of San Andreas LFE families. Red star indicates epicentre of 2004 Parkfield Earthquake.

4. Recurrence Pattern of Episodic Events
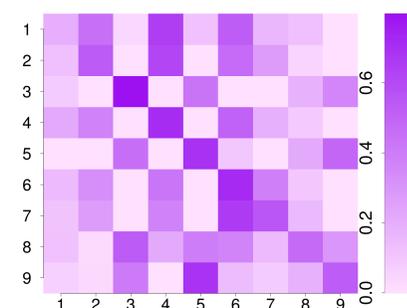
▶ Subsystems - Background activity (states 3, 5, 8 and 9) alternated with episodic bursts (states 1, 2, 4, 6, and 7).
▶ Accumulation of strain that is released in a burst, increased activity linked to slip movement.
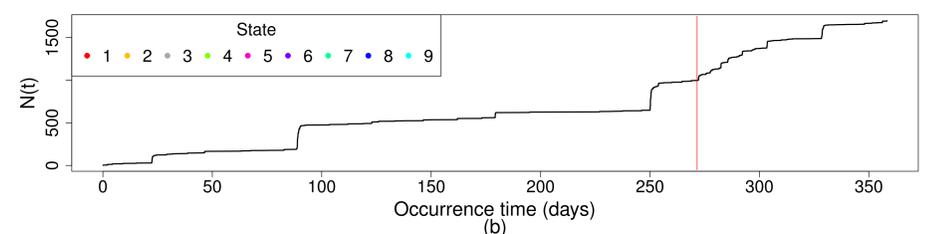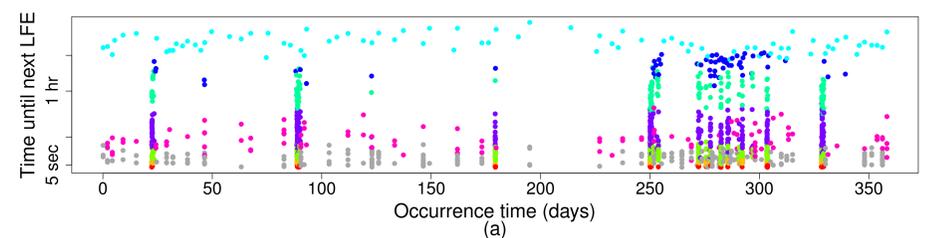
Figure 2:Transition probabilities between states.

Figure 3:LFE events recorded in 2004 (a) classified by the Viterbi algorithm and (b) cumulative number of events. Red line indicates Parkfield earthquake on 28 September 2004.

6. Patterns of Activity Migration

▶ Probability of transitions in continuous time between generating locations.
▶ Grouped using hierarchical agglomerative clustering (Manhattan $\sum_i |t_i - s_i|$) to identify locations with high interaction.
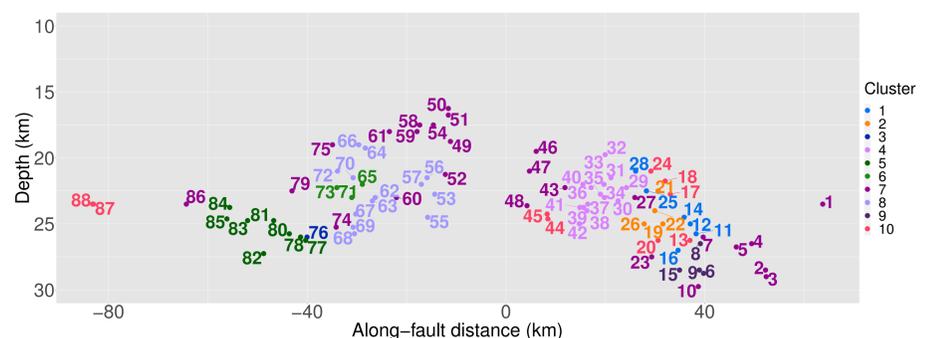

Figure 6:LFE generating locations coloured and numbered by assigned clusters.

Acknowledgments