Do the repeating earthquakes at Parkfield talk to each other?

Kate Huihsuan Chen, Roland Bürgmann, Robert M. Nadeau
Berkeley Seismological Laboratory, University of California, Berkeley, CA 947204760, USA

Contact: katepili@gmail.com

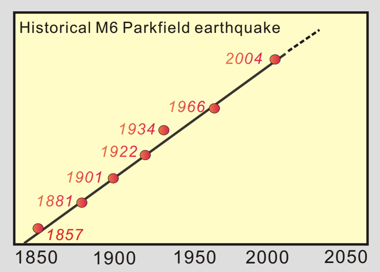
Abstract

The large population of characteristically repeating earthquakes at Parkfield provides a unique opportunity to study how these asperity ruptures interact with each other and nearby non-repeating earthquakes. Here we analyze M -0.4 ~ 3.0 repeating earthquake sequences to examine the variation of recurrence properties in space and time. We find that 67% of quasi-periodic repeating sequences (i.e., coefficient of variation in recurrence interval less than 0.3) correspond to zones of low seismicity, suggesting that these more regular repeating events are more isolated in space and from perturbing stress changes. We find that closely spaced repeating sequences show evidence of strong interaction in time, reflected in temporally clustered event recurrences. The temporal correspondence appears to be a function of separation distance from nearby earthquakes rather than the relative size of the events. The response of the earthquakes to the occurrence of large earthquakes provides the clearest documentation of the interaction process. Accelerations of repeating sequences are associated with the significant seismic moment release in the vicinity, and following the 2004 Parkfield earthquake, a large number of sequences exhibit accelerated recurrence behavior. The characteristically decaying afterslip pattern is not obvious for some of the repeating sequences located close to the largest co-seismic slip area, suggesting either that the stress changes are very heterogeneous, or that the rupture erased or shut off some of the sequence source areas. Building on the above observations, we will be able to develop mechanical models that test the extent to which fault interaction in the form of static stress changes and transient postseismic fault creep produces the observed aperiodicity in the occurrence of these events, and furthermore, attempt to improve predictions of the times of future event repeats.

Scientific Question

What determines the timing of earthquake recurrences and their regularity?

This question cannot be answered without a statistically sufficient observations of recurrence properties in natural earthquake populations.



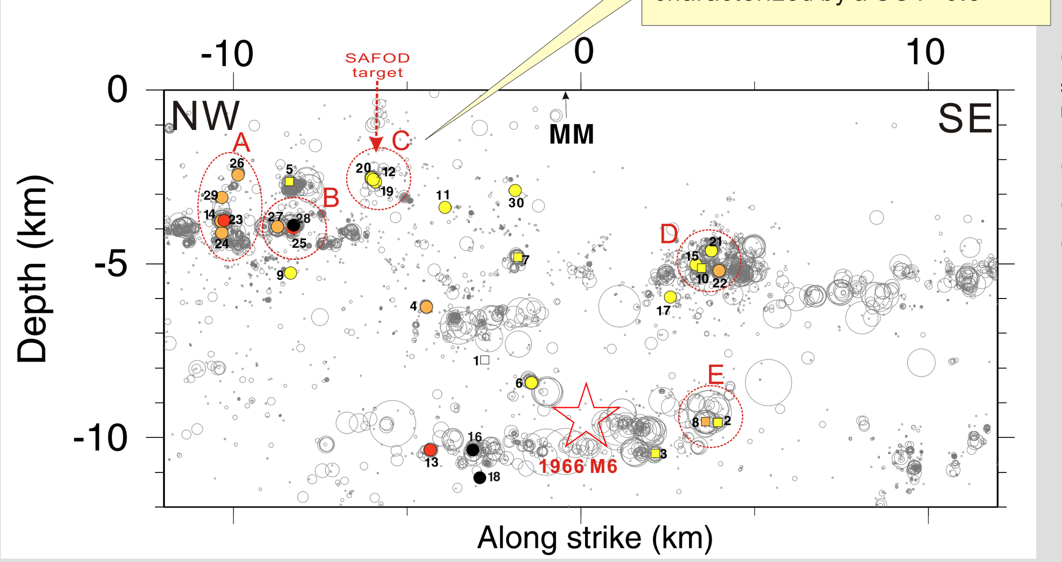
Repeating Earthquake Data

Repeating earthquake data:
NCSN (1984-2004) 30 M1.3~3.0 sequences (178 events) [*Nadeau and McEvilly*, 2004]
HRSN (1987-1998) 187 M-0.4 ~ +1.7 sequences (1123 events) [*Nadeau and McEvilly*, 2004]
HRSN updated (1987-Sep. 15 2006) 25 M-0.51~2.16 sequences (462 events) [*Nadeau et al.*, 2005]

Background seismicity:
1984-2005 Double difference earthquake catalog
[*Waldhauser et al.*, 2004; *Thurber et al.*, 2005]

(a) NCSN repeating earthquake sequences (RESs)

50% of the NCSN REQSs are characterized by a COV<0.3

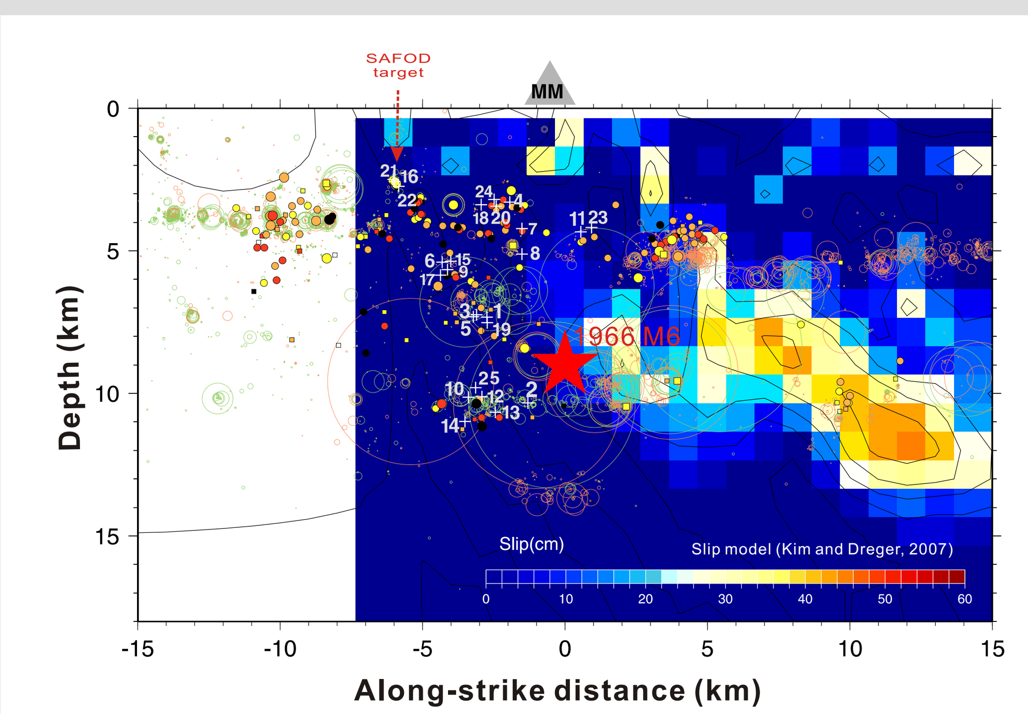


Coefficient of variation = standard deviation divided by the mean of recurrence interval (Tr)

COV=0 : Perfect periodicity
COV~1 : Poissonian recurrence
COV>1 : Temporal clustering

1984-2005 Relocated seismicity
Number <5 NCSN repeater
Number >=5 NCSN repeater
COV = 0.0 (pair)
COV = 0.0 - 0.3
COV = 0.3 - 0.5
COV = 0.5 - 0.7
COV = 0.7 - 1.0

(b) NCSN + HRSN repeating earthquake sequences (RESs)



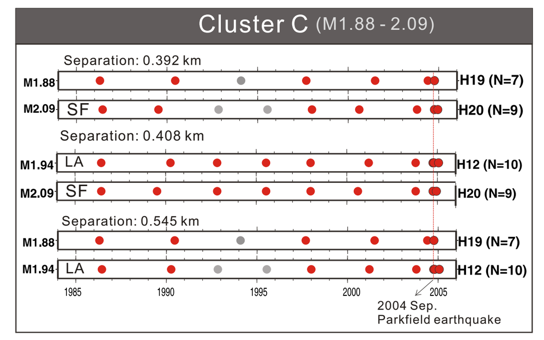
Repeating earthquake sequences
[*Nadeau and McEvilly*, 2004]
HRSN updated repeater
NCSN and HRSN repeater
Number less than 5
Number larger than 5
COV: 0.0-0.3 · COV: 0.5-0.7
COV: 0.3-0.5 · COV: 0.7-1.0

Seismicity
[*Waldhauser et al.*, 2004; *Thurber et al.*, 2006]
Pre- PK : 1984 - 27Sep.2004
Post-PK : 28Sep.2004 - 2005

Fig. 1. (a) Fault-parallel section showing background seismicity and NCSN-derived repeating sequences. Fill color/shades are keyed to the COV in recurrence interval. Dashed red circles indicate the clusters of interest (with inter-repeater distances of less than 1 km). Number indicate the ID of NCSN repeating sequences. (b) Fault-parallel section section showing the distribution of HRSN and NCSN repeating sequences (filled circles), updated HRSN repeating sequences (white crosses), background seismicity (open circles color coded for pre- and post-2004 earthquake), 1966 M6 hypocenter, and their relationship to the slip distribution of the 2004 Parkfield mainshock [Kim and Dreger, 2007]. Fill color/shades are keyed to the COV in recurrence interval. Number indicate the ID of the updated 25 HRSN repeating sequences.

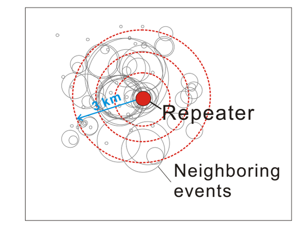
1. What controls the aperiodicity?

RES: Repeating earthquake sequence
COV: Coefficient of variation



COV<0.2 Repeating earthquake sequences (RESs)

Role of surrounding earthquakes ?



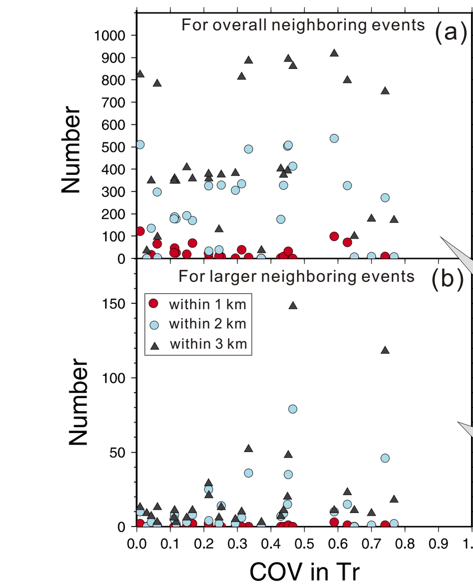


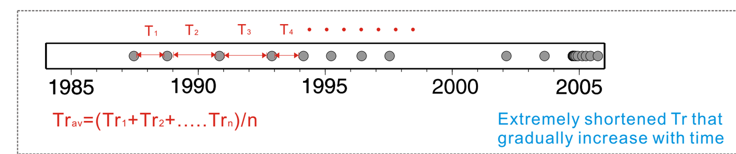
Fig. 2. COV in recurrence interval of each repeating sequence versus number of its neighboring earthquakes in the distance of 1 km (red circles), 2 km (blue circles), and 3 km (black triangles). (a) Overall neighboring earthquakes are presented. (b) Only the earthquakes with larger magnitude than the target repeater are presented.

Simply considering the total number of nearby events does not produce a notable trend.

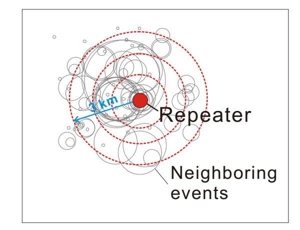
RESs with a COV < 0.3 have a smaller number of larger events in their immediate vicinity.

More isolated RESs tend to recur in a regular manner.

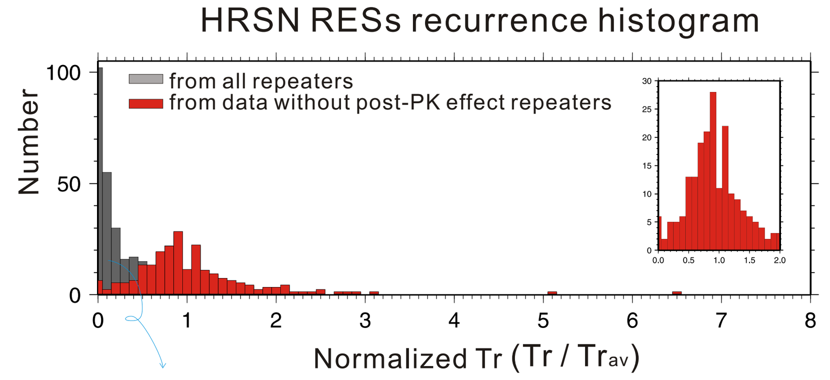
2. What controls recurrence acceleration?



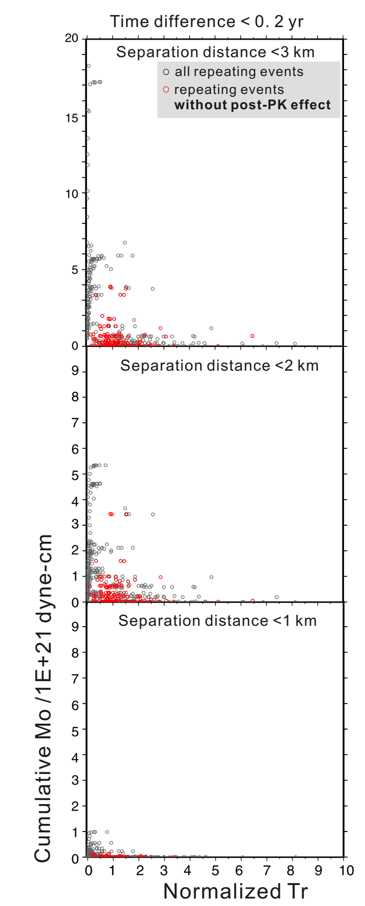
Do the nearby M>3 events correlate with unusually short Tr?



HRSN RESs recurrence histogram



extremely short Tr are mostly from post-PK repeating events



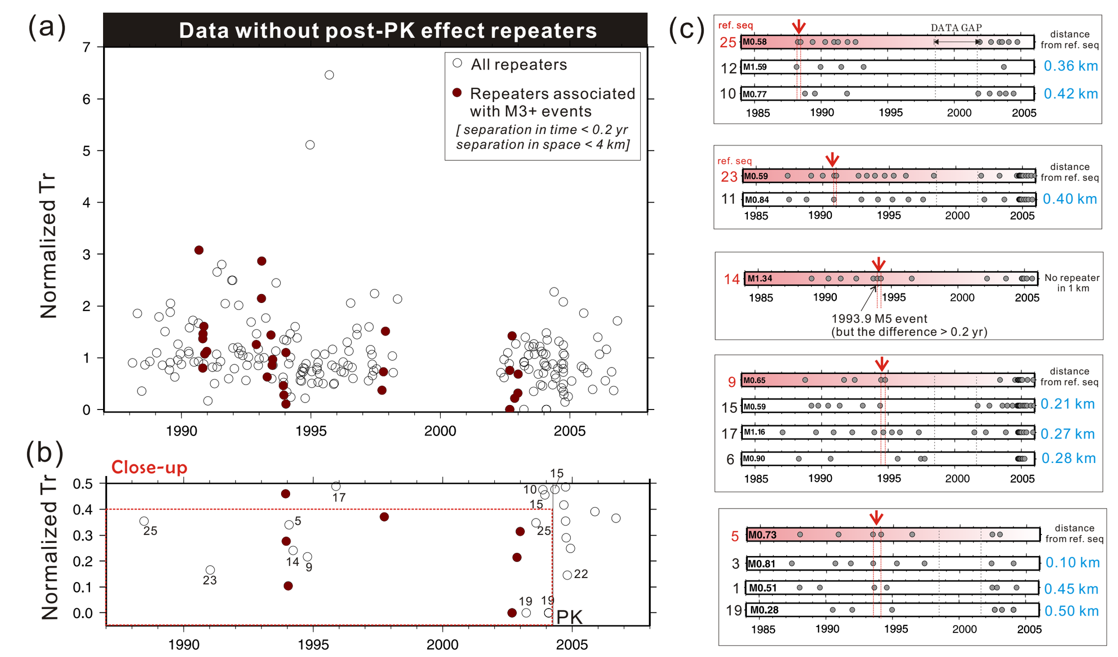
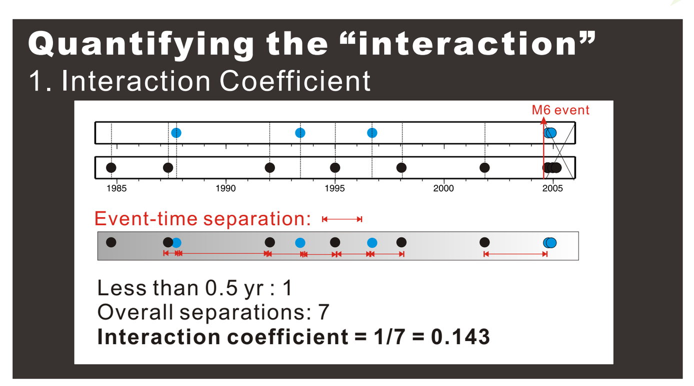


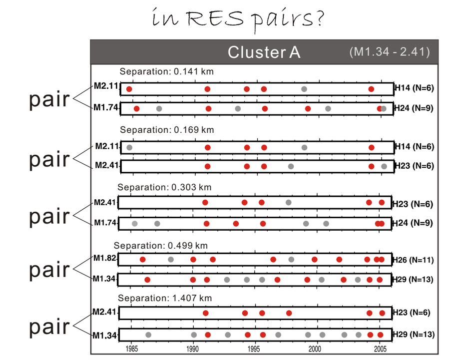
Fig. 3. (a) Normalized recurrence interval as a function of year. Recurrence data associated with nearby M3+ events are highlighted in red.(b) Close-up of short normalized Tr of less than 0.5. Number indicates the RES's identity. (c) Event chronologies of the target RES (highlighted in pink) and the RESs within 1 km from the target RES.

Short recurrence intervals are associated with nearby moment release of M>3 events.

3. Do nearby RESs correlate in time?

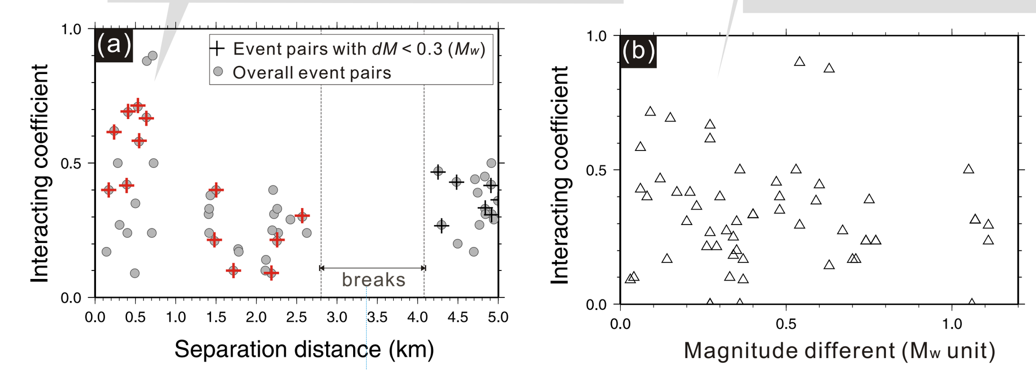


Closeness of individual events in RES pairs?



The trend of interaction coefficient decreasing with increasing separation becomes clearer for the pairs with small size difference (dM<0.3).

A large magnitude difference within a cluster does not correspond to a low interaction coefficient.



The breaks may suggest the temporal correlation becomes insignificant when the separation distance > 3 km, for the M<3 earthquakes we consider.

Fig. 4. (a) Interaction coefficient between NCSN RESs pairs vs. separation distance. Filled circles indicate overall RES pairs in Clusters A to E. Crosses mark the pairs with similar magnitude (magnitude difference (dM) of less than 0.3 Mw unit). (b) Interaction coefficient between NCSN RESs pairs vs. magnitude difference.

Closely adjacent RESs with comparable size show strong correlation in time.

4. Do nearby RESs have similar recurrence properties?

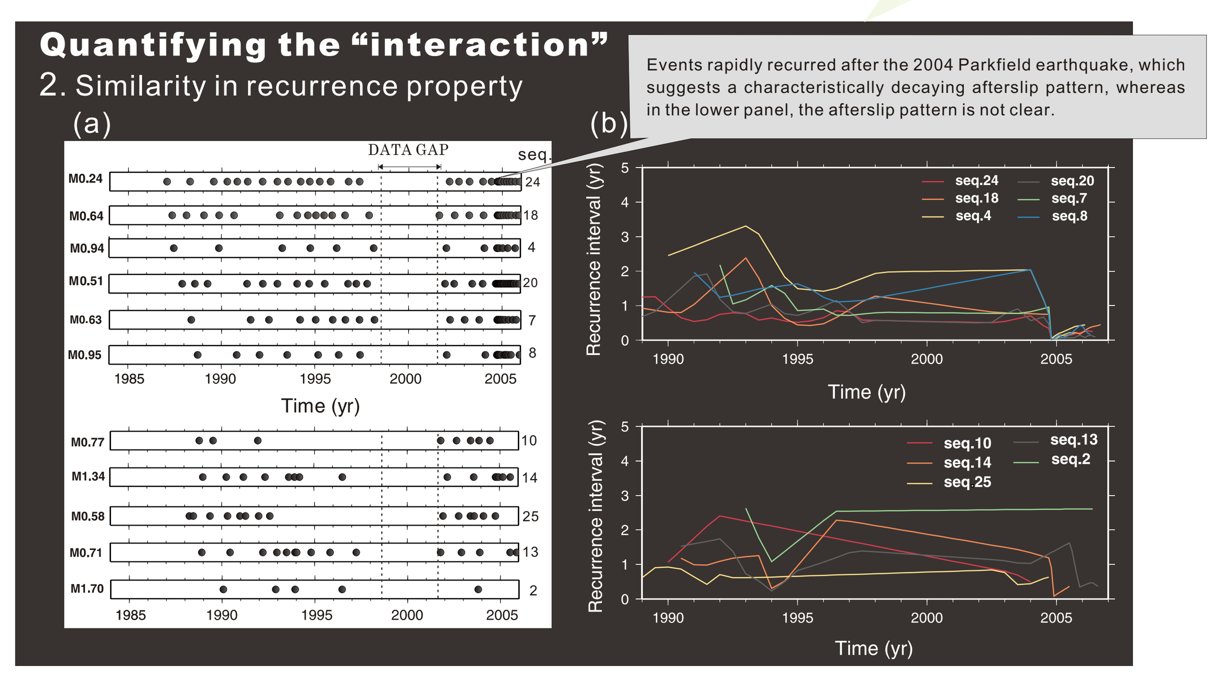
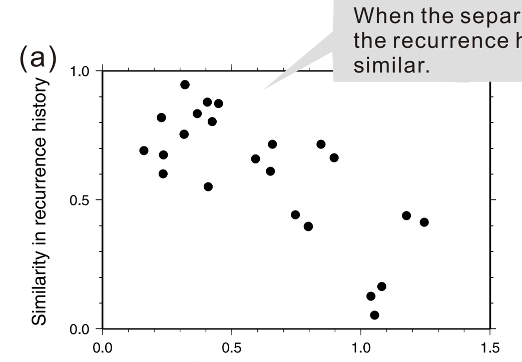


Fig. 5. (a) Event chronology for two HRSN REQS clusters (see white crosses with number for locations in Fig. 1b). (b) Inter-event time spans (recurrence interval) as a function of time for each RES in the two clusters. The similarities between recurrence history curves are illustrated by cross-correlation coefficient.

When the separation distance is small, the recurrence histories appear to be similar.



The relationship between recurrence history and magnitude difference is unlikely to follow a linear pattern

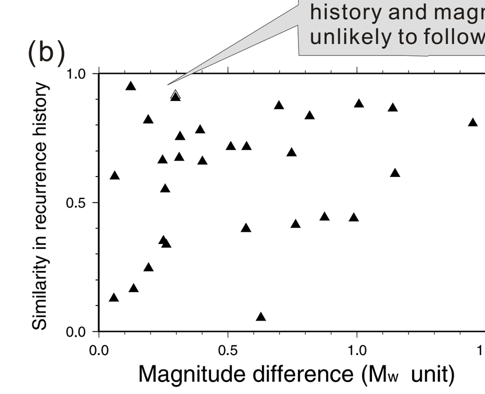


Fig. 6. (a) Similarity in recurrence history (Figure 4b) between HRSN RES pair as a function of separation distance. (b) Similarity in recurrence history curve as a function of magnitude difference.

Closely adjacent RESs show similar recurrence history.

References

- Kim, A., and D. S. Dreger (2008), Rupture process of the 2004 Parkfield earthquake from near-fault seismic waveform and geodetic records, Journal of Geophysical Research, doi:10.1029/2007JB005115, in press.
- Nadeau, R. M., and T. V. McEvilly (2004), Periodic pulsing of characteristic microearthquakes on the San Andreas fault, Science, 303, 220-222.
- Nadeau, R. M., M. Traer, and A. Guilhem (2005), Repeating earthquake and nonvolcanic tremor observations of aseismic deep fault transients in Central California, Eos Trans. AGU, 86(52), Fall Meet. Suppl., Abstrac G44A-01.
- Thurber, C., H. Zhang, F. Waldhauser, J. Hardebeck, A. J. Michael, and D. Eberhart-Phillips (2007), Three-Dimensional Compressional Wavespeed Model, Earthquake relocations, and Focal Mechanisms for the Parkfield, California, Bull. Seism. Soc. Am., 96, S38-S49.
- Waldhauser, F., W. L. Ellsworth, D. P. Schaff, and A. Cole (2004), Streaks, multiplets, and holes: High-resolution spatio-temporal behavior of Parkfield seismicity, Geophys. Res. Lett., 31, doi:10.1029/2004GL020649.

Future Work - Mechanical Model

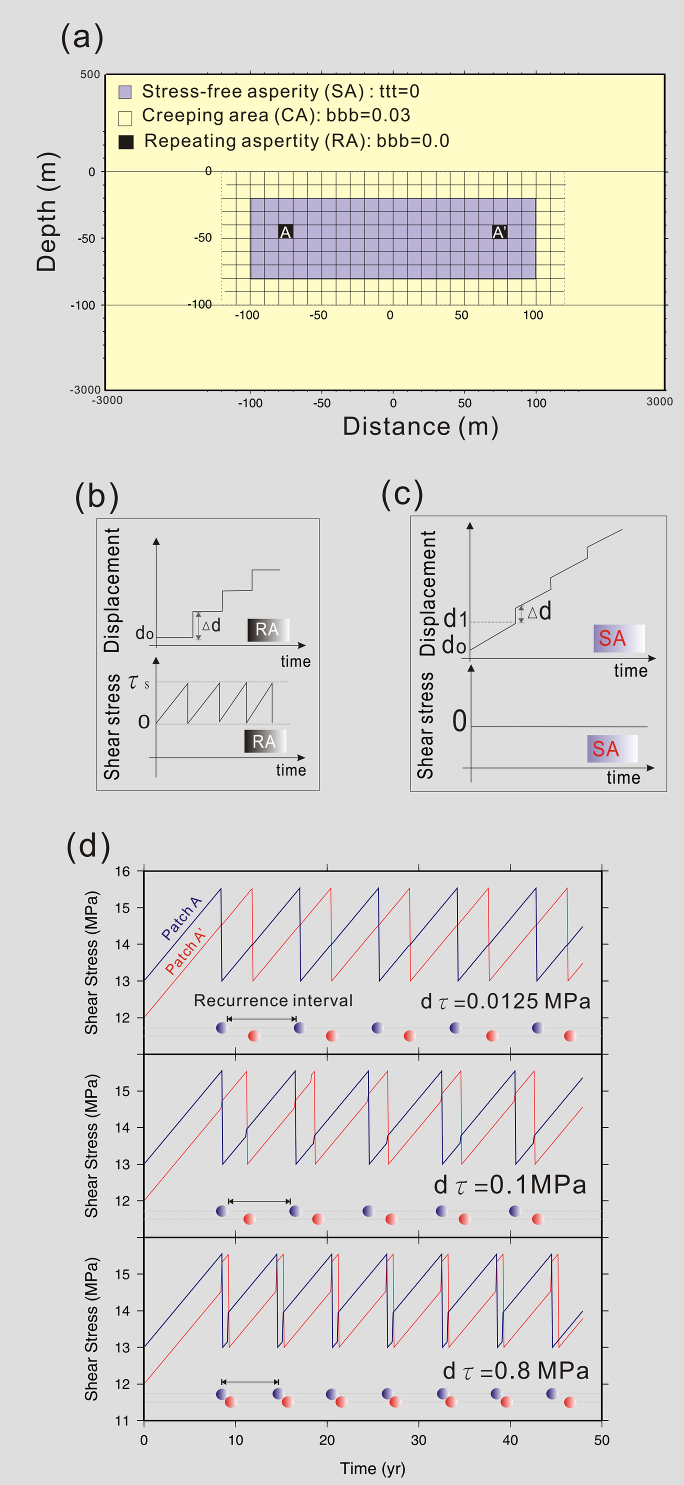


Fig. 7. (a) Schematic planar representation of the fault model in cross-section. (b-c) Schematic diagrams of stress versus time and displacement versus time at isolated repeatable asperity (RA) and freely slipping zones (SA). (d) Evolution of shear stress of two RA (solid circles indicate earthquakes). Stress evolution as a function of stress increment induced by the other rupture (dτ), for two patches have the same size and same stressing rate.