Static stress triggering explains the empirical aftershock distance decay

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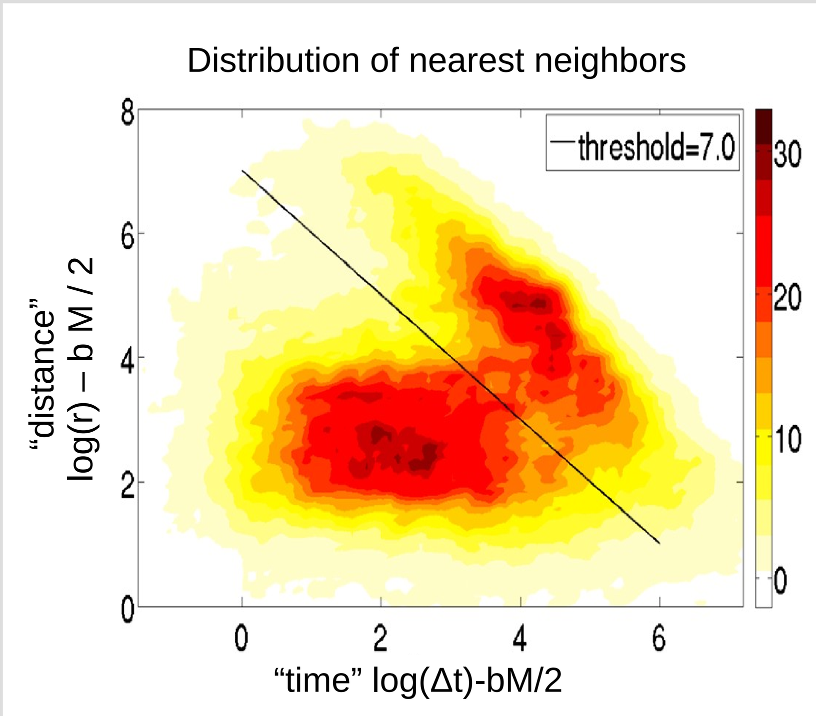
Abstract: The shape of the spatial aftershock decay is sensitive to the triggering mechanism and thus particularly useful for discriminating between static and dynamic stress triggering. For California seismicity, it has been recently recognized that its form is more complicated than typically assumed consisting of three different regimes with transitions at the scale of the rupture length and the thickness of the crust. The intermediate distance range is characterized by a relative small decay exponent of 1.35 previously declared to relate to dynamic stress triggering. We perform comprehensive simulations of a simple clock-advance model, in which the number of aftershocks is just proportional to the Coulomb-stress change, to test whether the empirical result can be explained by static stress triggering. Similarly to the observations, the results show three scaling regimes. For simulations adapted to the depths and focal mechanisms observed in California, we find a remarkable agreement with the observation over the whole distance range for a fault distribution with fractal dimension of 1.8, which is shown to be in good agreement with an independent analysis of California seismicity.

Data:
Southern California relocated catalog (Hauksson et al. 2012)

Selection of aftershocks based on nearest space-time distance $n_{ij} \sim \Delta t\, r^d\, 10^{-bM}$ between an event and all preceding events where d is the fractal dimension (Baiesi & Paczuski 2004; Gu et al. 2013).



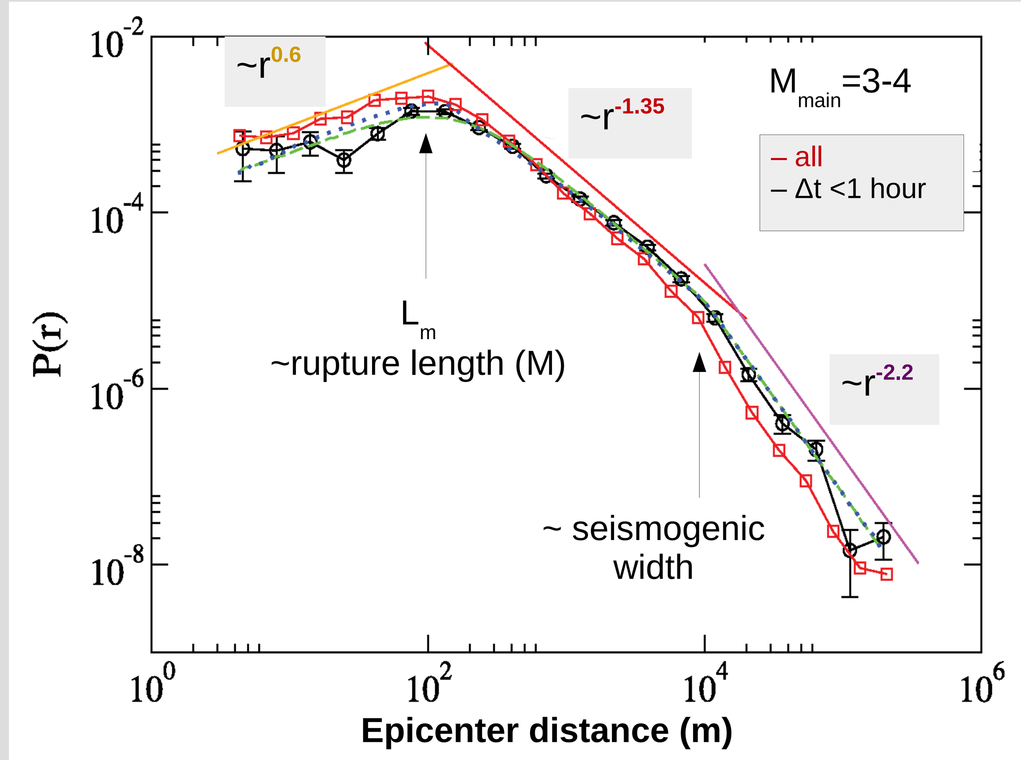
Observed Decay

3 scaling regimes with transitions at:

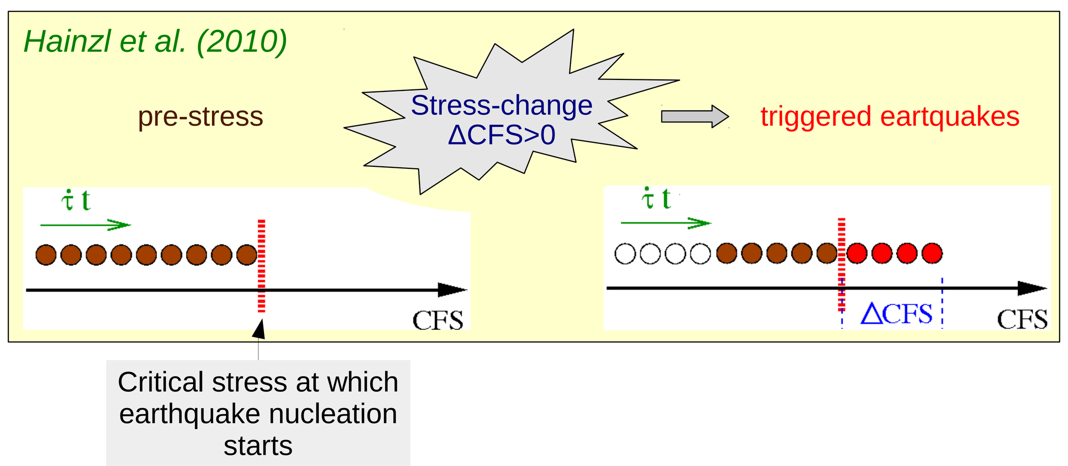
- rupture dimension
- seismogenic width

$$P_m(r) = \begin{cases} \alpha \dfrac{q r^{\gamma}}{L_m^{\gamma+1}\left(\frac{r^{\gamma+1}}{L_m^{\gamma+1}}+1\right)^{1+\frac{q}{\gamma+1}}} & \text{if } r < 10\text{km},\\ \beta \dfrac{d r^{\gamma}}{L_m^{\gamma+1}\left(\frac{r^{\gamma+1}}{L_m^{\gamma+1}}+1\right)^{1+\frac{d}{\gamma+1}}} & \text{if } r > 10\text{km}. \end{cases}$$

γ=0.6 q=0.35 d=1.2



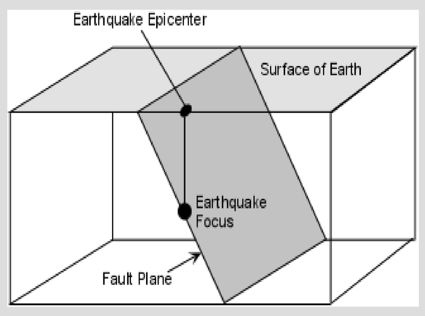
Static Stress Triggering



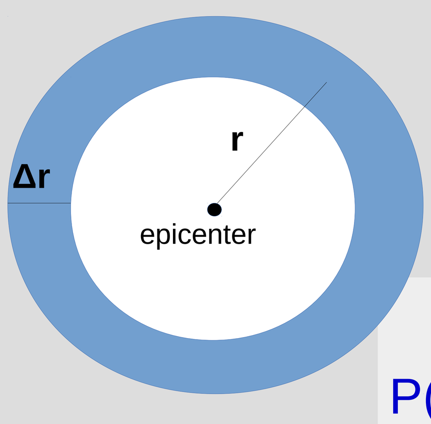
Clock advance - time needed to achieve ΔCFS by tectonic loading: $\Delta t = \Delta CFS / \dot{\tau}$

Number of triggered events: $N_a = r\,\Delta t = (r/\dot{\tau})\,\Delta CFS$ if ΔCFS>0, else 0

Analysis for synthetic mainshock ruptures:



- select magnitude M
- uniform (or fractal) slip
- empirical relations between M and slip/area
- epicenter randomly within rupture area
- effective friction coefficient of 0.5
- elastic half-space (or layered half-space)

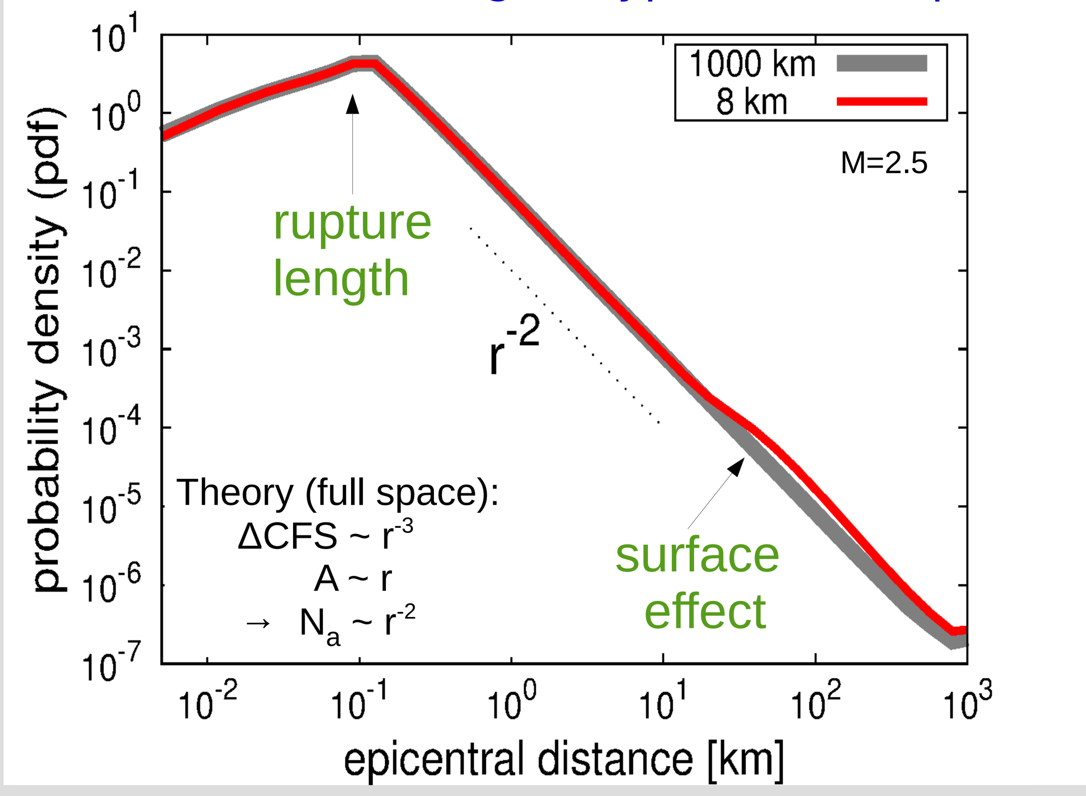


$A \sim (r+\Delta r/2)^d - (r-\Delta r/2)^d$

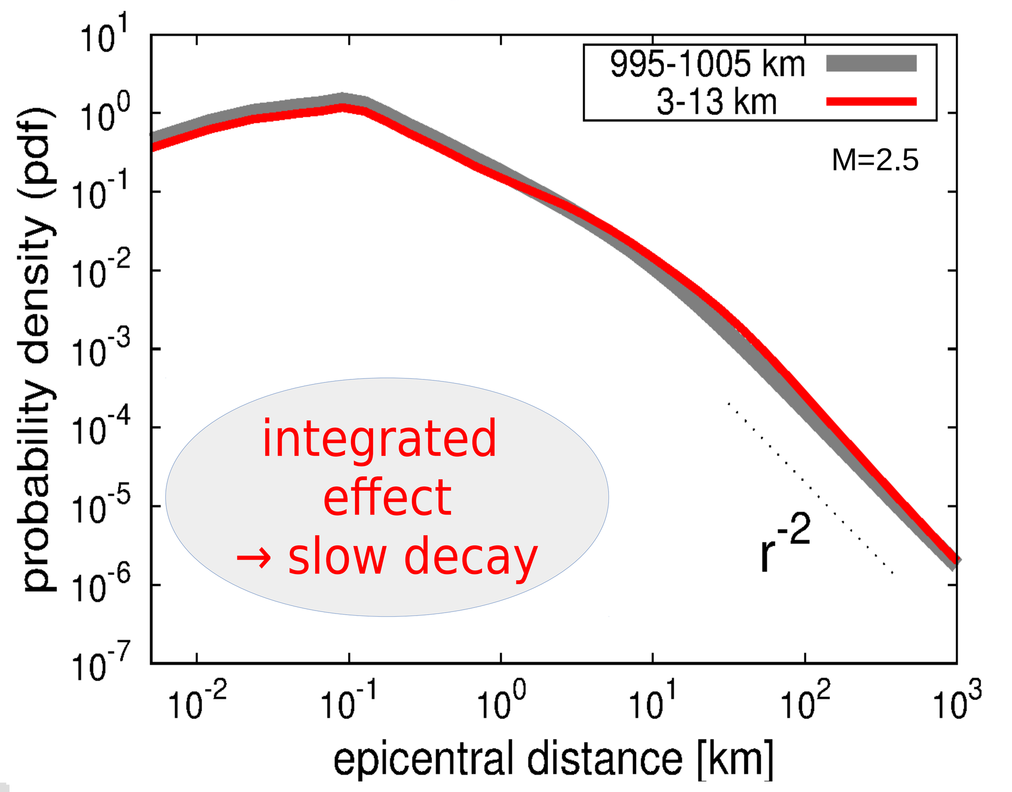
A: seismogenic area
d: fractal fault dimension (uniform: d=2)

Linear aftershock density:
$P(r) \sim \overline{\Delta CFS(r)\, H(\Delta CFS)}\ A / \Delta r$

Aftershocks occuring at hypocentral depth

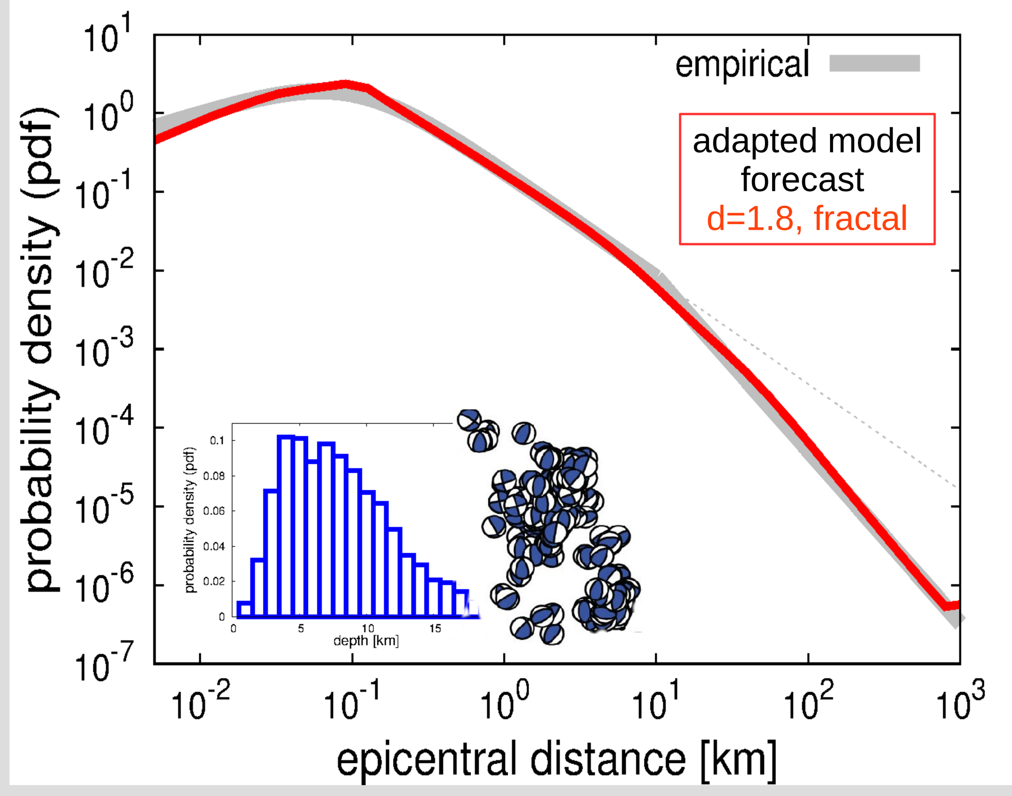


... in seismogenic depth interval

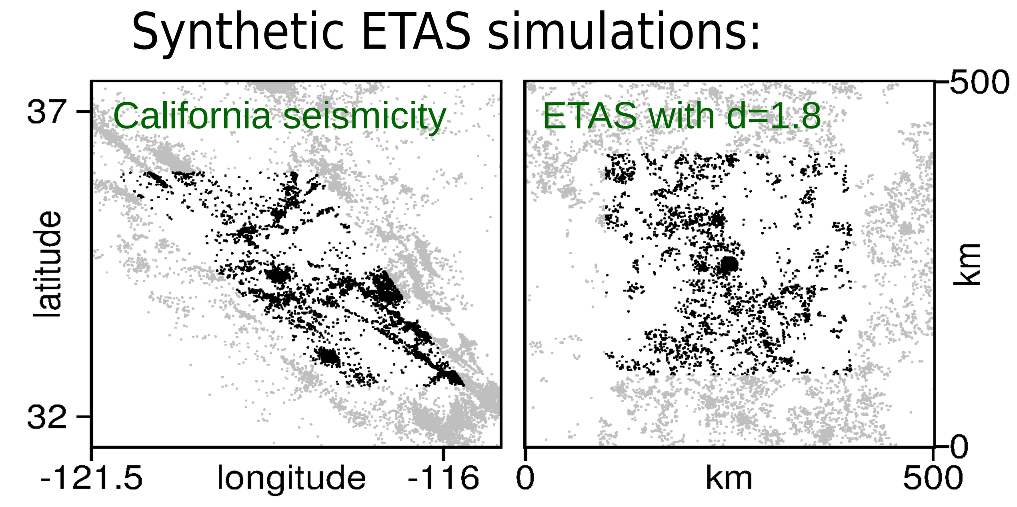


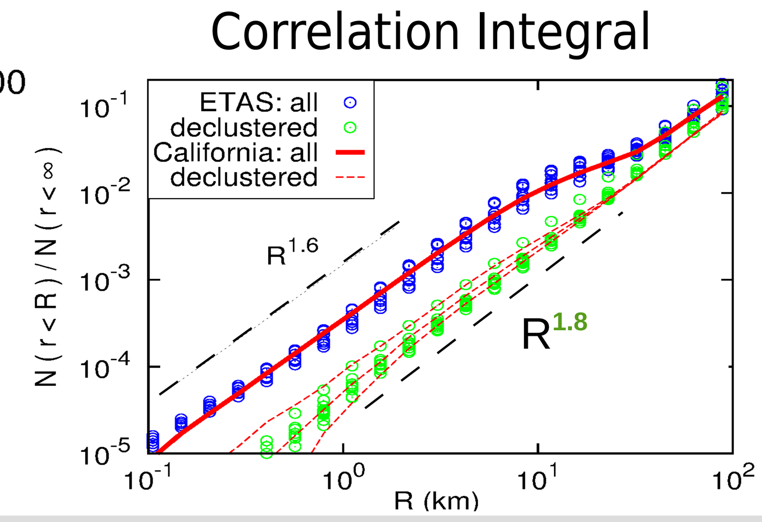
Results:

- r^{-2} decay only for a single depth layer
- much smaller decay due to aftershocks with different depth
- transition at distance ~ seismogenic width
- effects of the free surface observable
- empirical distribution reproduced for background distribution with d=1.8



Independent test of a fractal dimension of d=1.8





Summary: Based on basic assumptions, the static stress triggering model can provide a straightforward forecast of the distance decay of aftershocks which is in excellent agreement with the empirical distribution of epicentral distances of aftershocks. The model can reproduce the three empirical scaling regimes of the distribution for a fractal dimension of 1.8 which is independently verified by an analysis of the epicenter distribution in southern California.This indicates that static stress changes are the dominant driving force for aftershocks recorded in the earthquake catalog.

References: Baiesi, M., M. Paczuski, Scale-free networks of earthquakes and aftershocks, PRE, 69, 066106, 2004.
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