香港中文大學
The Chinese University of Hong Kong

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The Cascading Foreshock Sequence of the Ms 6.4 Yangbi Earthquake in Yunnan, China

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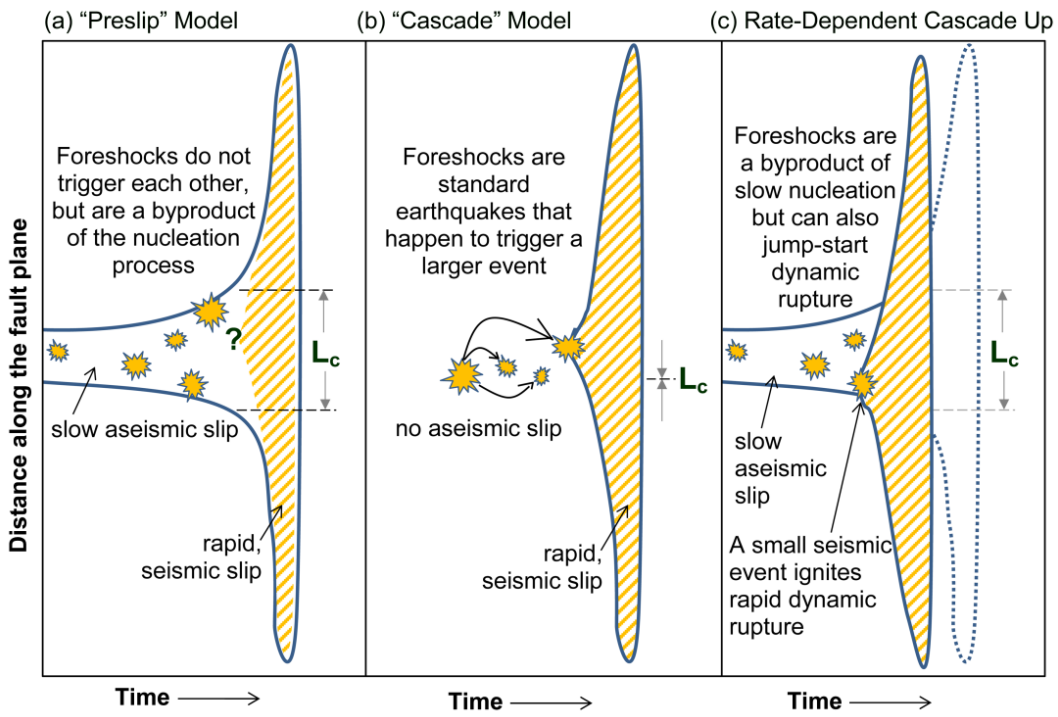
Earthquake initiation models



[McLaskey, 2019]

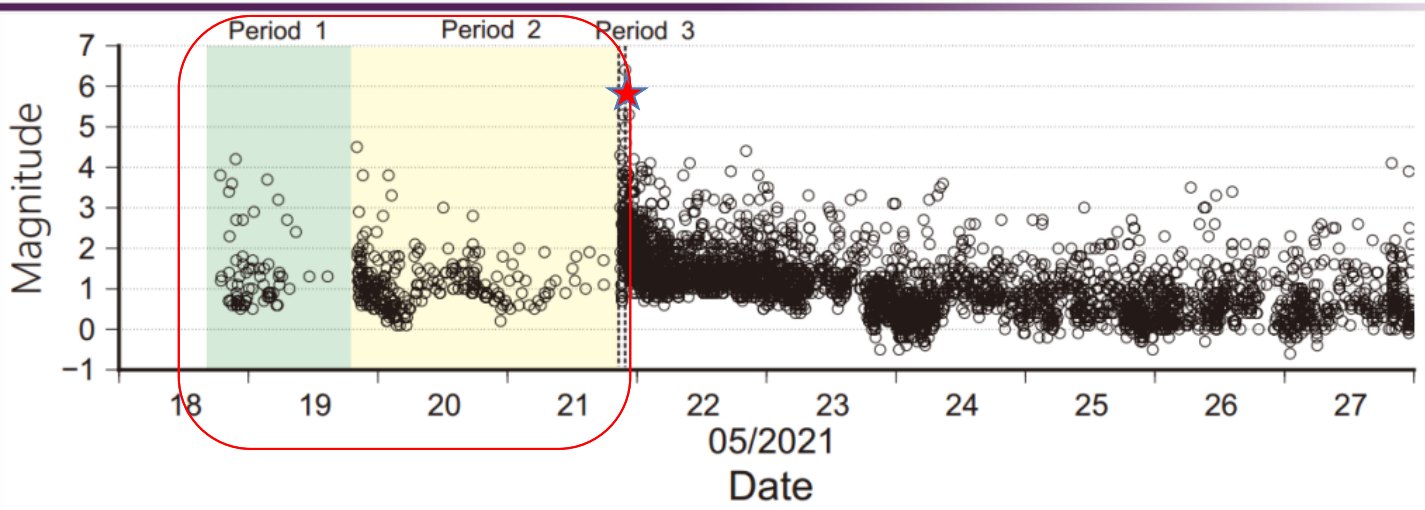
(a) foreshocks are are triggered by **aseismic slip** over an extended area surrounding the mainshock hypocentre (nucleation zone);

(b) foreshocks are triggered by **neighbour-to-neighbour stress transfer** and trigger a large earthquake by random chance;

(c) Contains attributes of both endmembers.

As no direct observations of preslip were available, the processes were usually inferred from seismicity and thus debates exist, mostly due to the insufficient resolution.

Life-saving 2021 Ms 6.4 Yangbi foreshocks

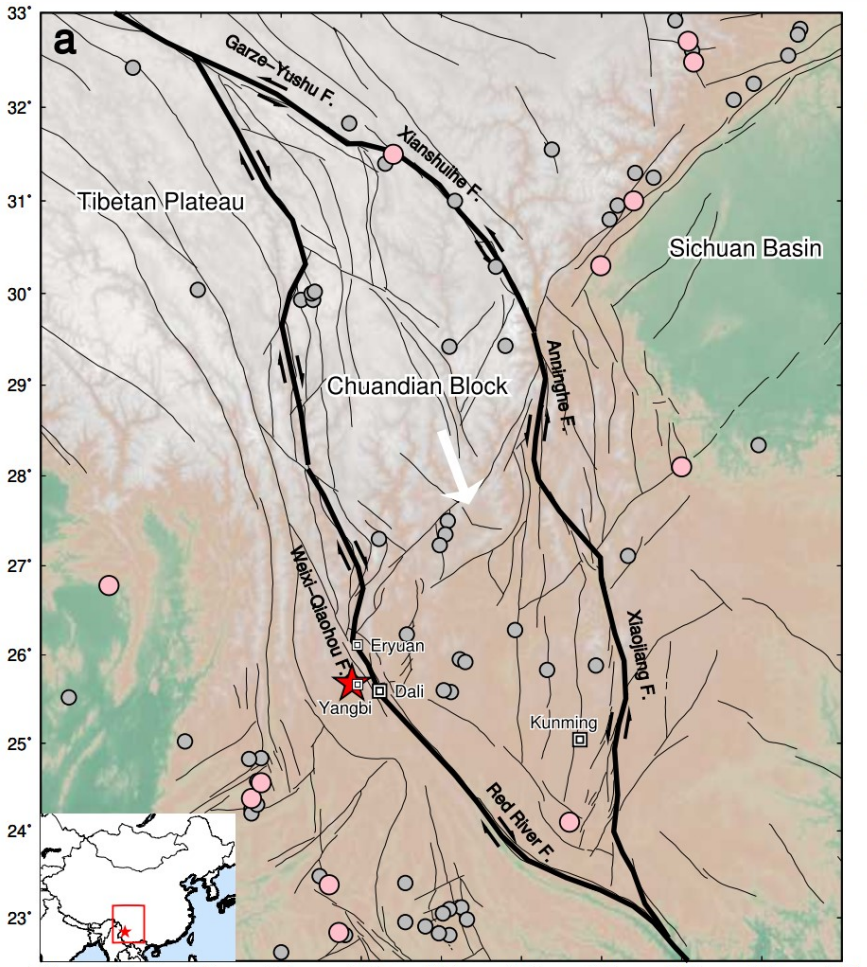


Seismicity started to increase significantly 3 days before the mainshock, with 5 events of magnitudes larger than 4.

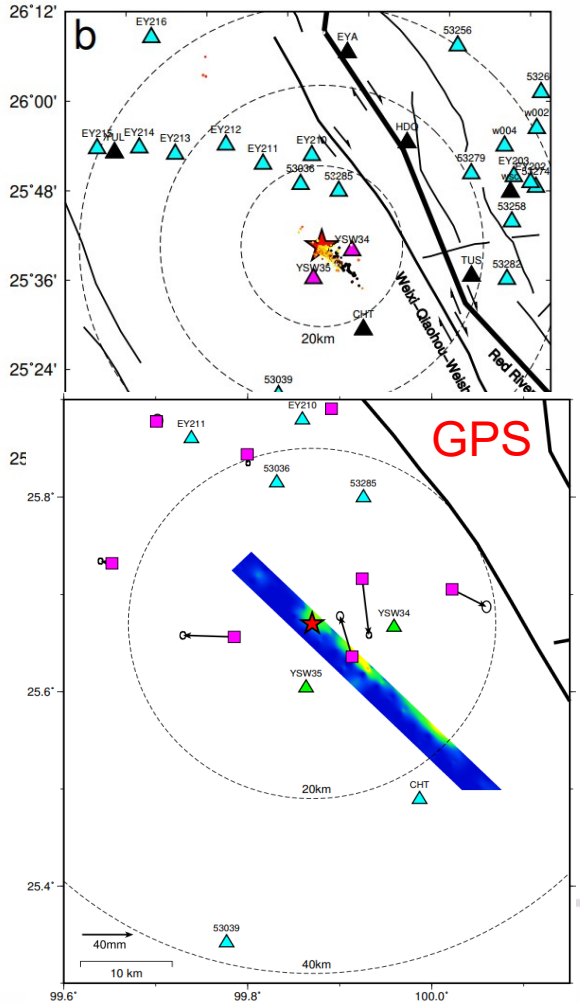
Local residents have stayed in tents or outside vulnerable buildings on May 20th

Well-recorded 2021 Ms6.4 Yangbi sequence

- An Ms 6.4 earthquake struck Yangbi, western Yunnan, China, on May 21, 2021.
- Seismic stations + GPS observations extremely close to the mainshock.

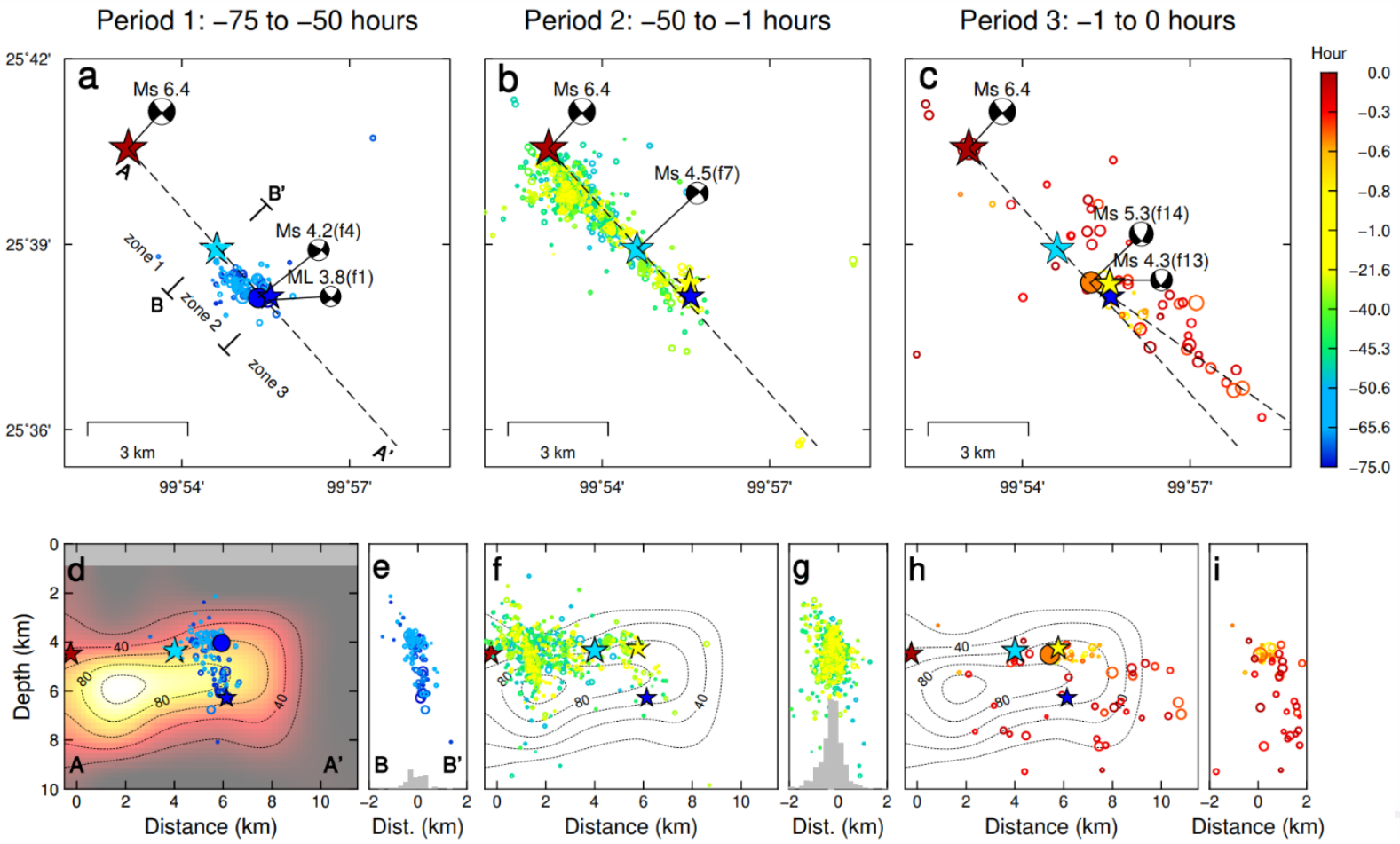


Seismic stations



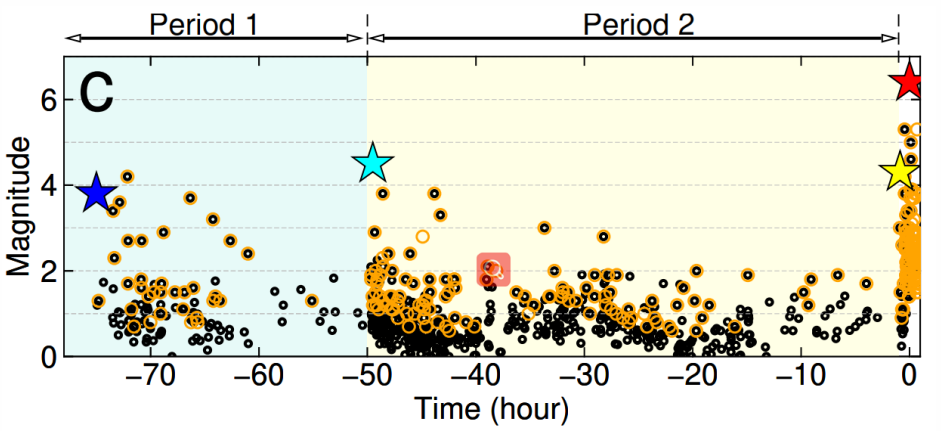
Spatiotemporal pattern of foreshocks

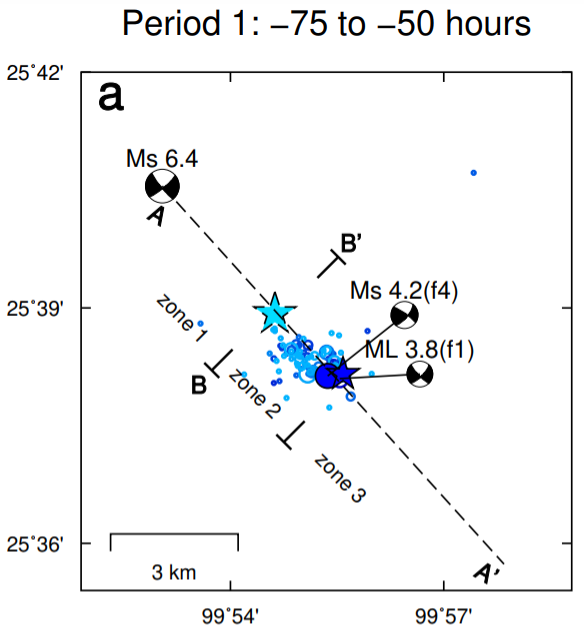
A total of 796 events with the magnitude of -0.1-5.3 were well relocated. Based on their spatial pattern, we divided the mainshock ruptured fault into zone 1, 2, 3



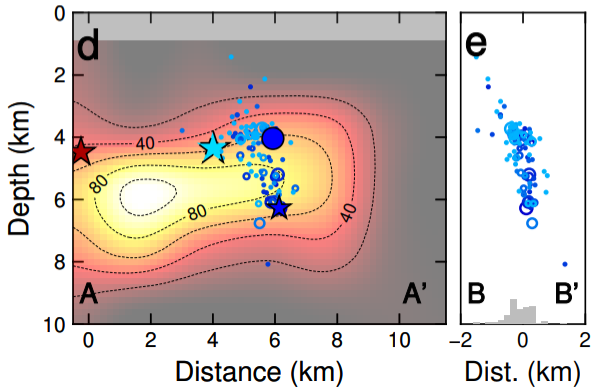
[Zhu, et al., 2022]

Cluster 1

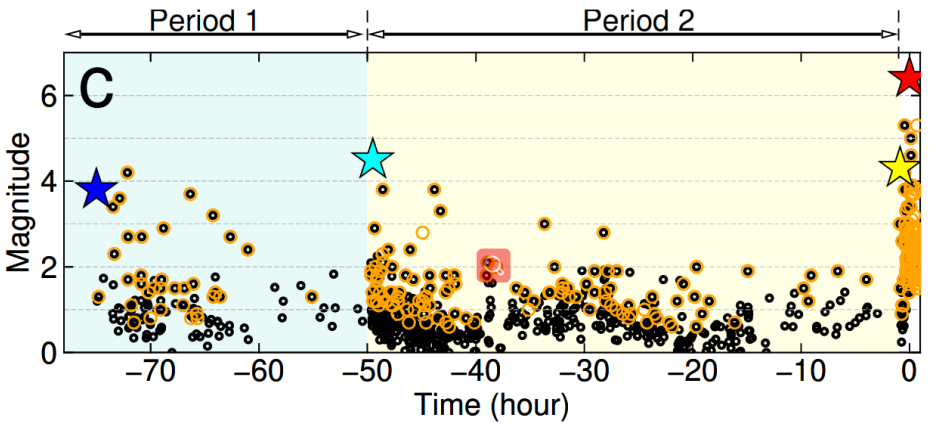




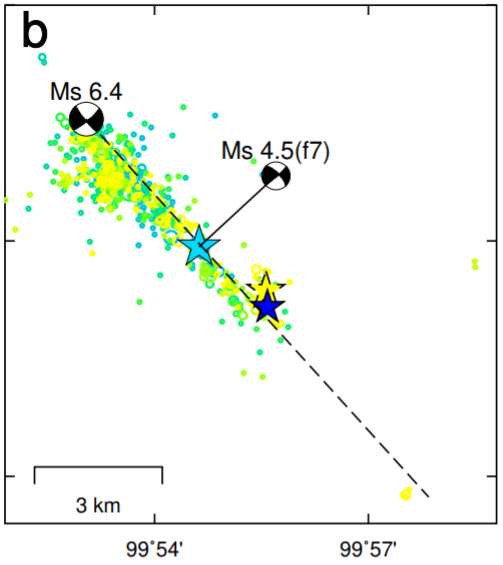
- Started with a ML 3.8 earthquake, shortly followed by an Ms 4.2 event.
- Confined within a 3-km segment along strike
- Spanned in depth of 3-7 km
- Located within 1 km normal to fault



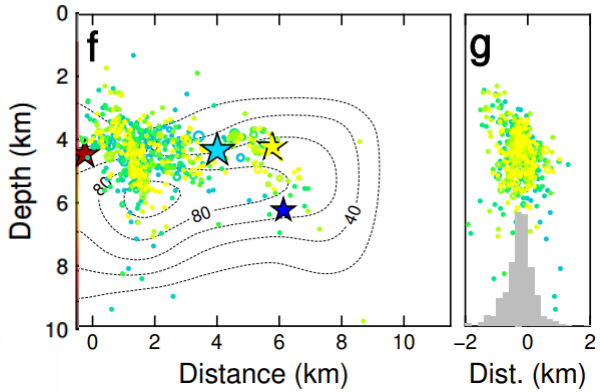
Cluster 2



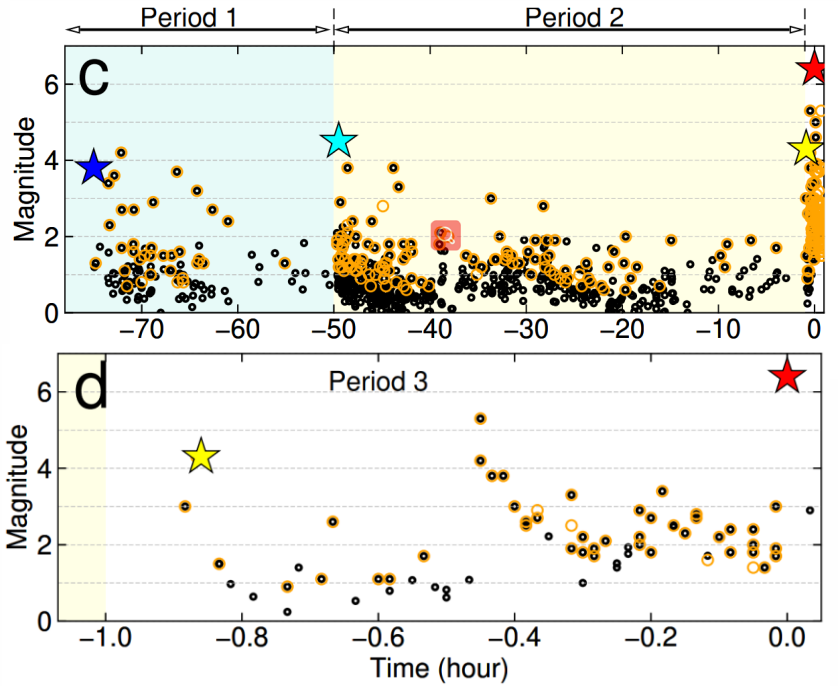
Period 2: –50 to –1 hours

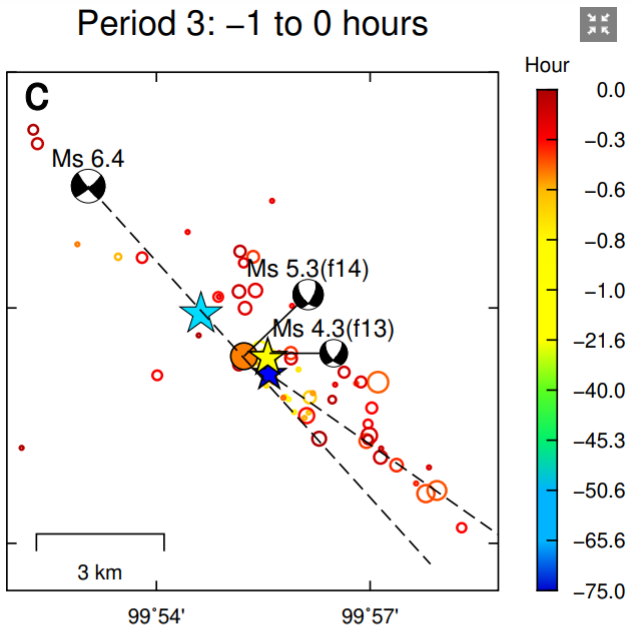


- Started with an Ms 4.5 event that located in the vicinity of the previous sequence.
- Ruptured the segment of 5 km, towards the mainshock hypocenter
- Spanned in depth of 3-6 km
- Located within ~1 km normal to fault

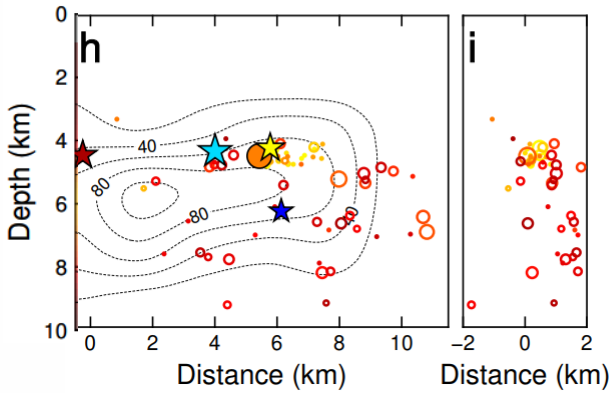


Cluster 3



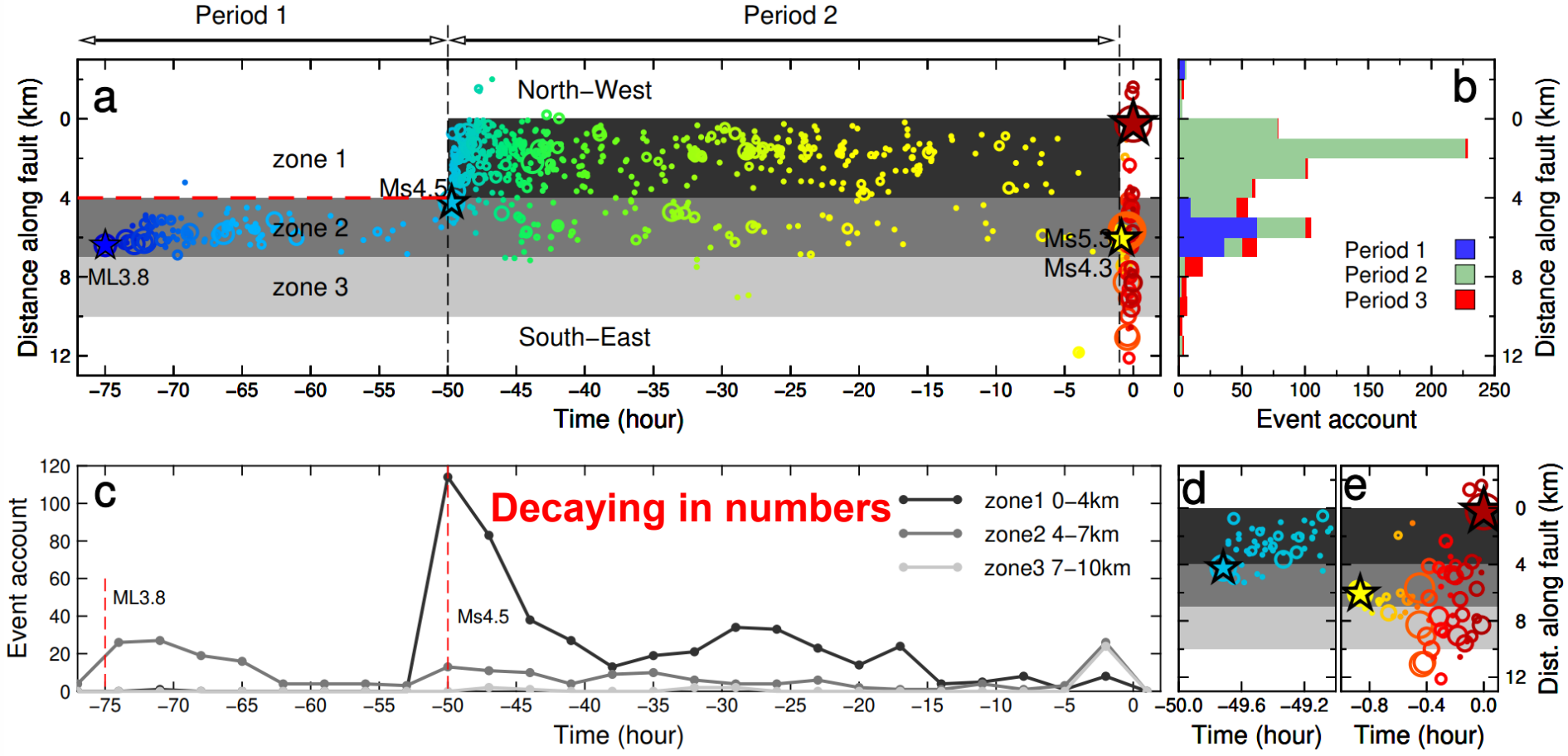


- Ruptured southeastward (zone 3), away from the mainshock hypocenter
- After the largest foreshock Mw 5.2, off fault seismicity on secondary faults or branches.



Foreshocks spatial temporal evolution

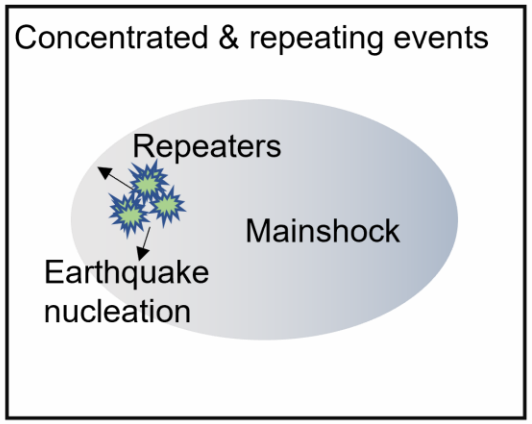
Intermittent episodes of foreshocks without an accelerating pattern leading up to the mainshock.



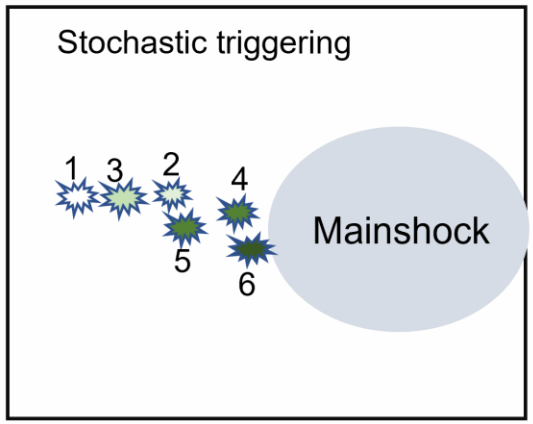
[Zhu, et al., 2022]

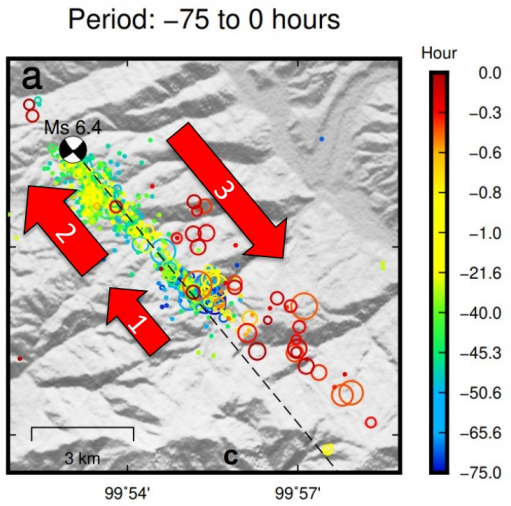
Favored model

a Mainshock pre-slip

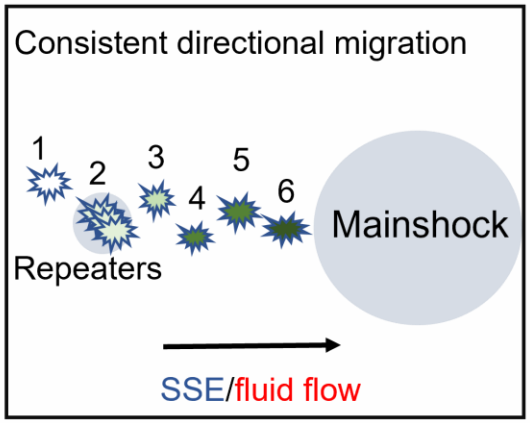


b Cascade Yes

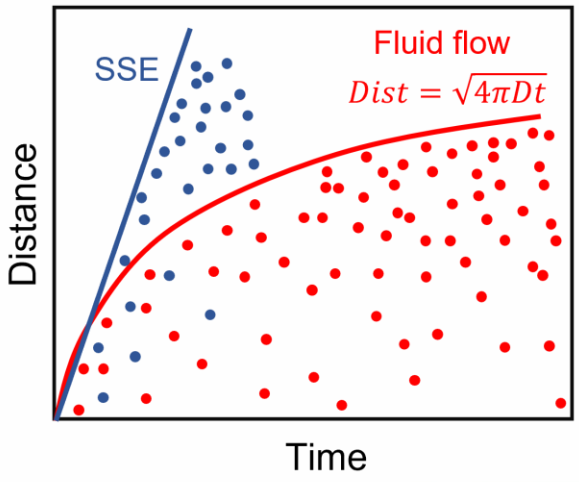




c Ambient SSE or fluid flow



d Migration pattern

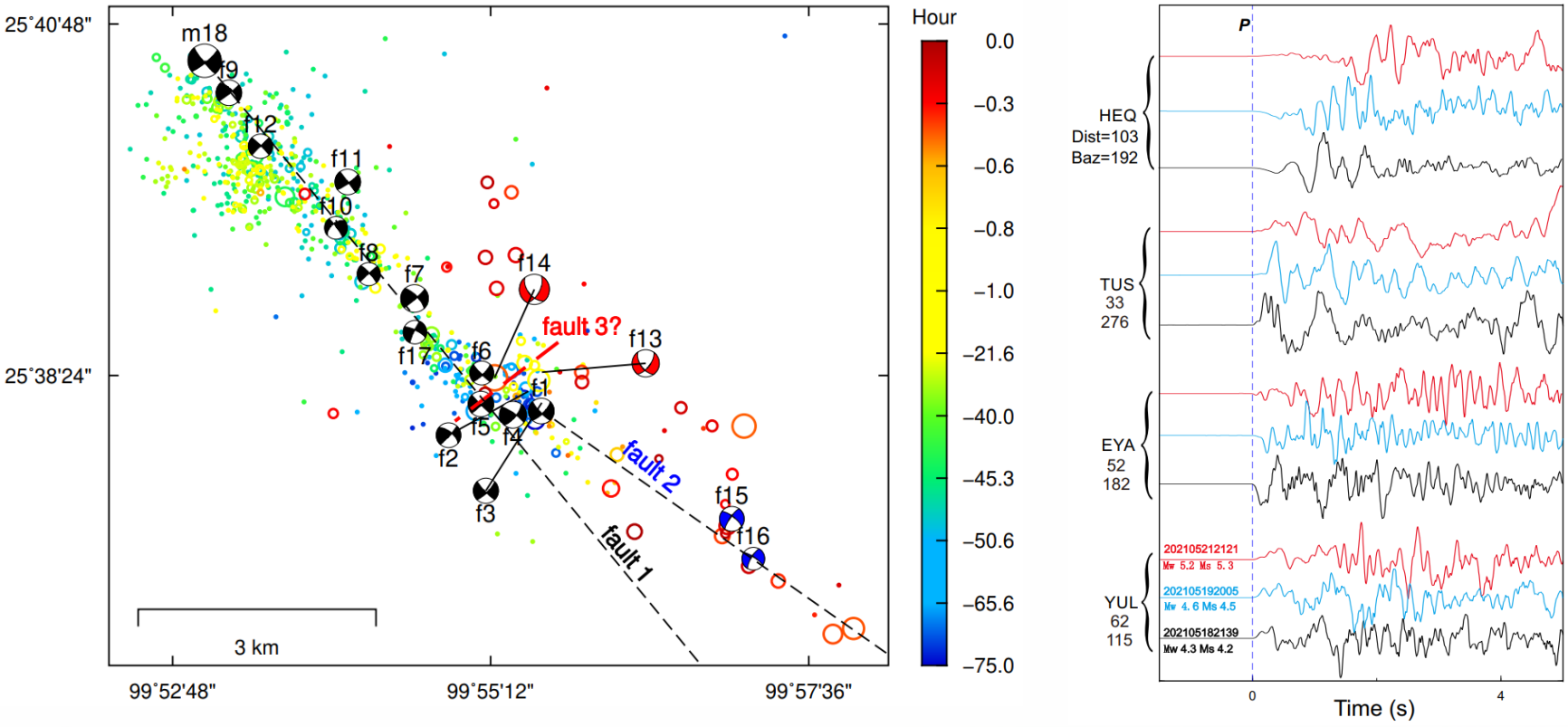


- lack of consistent foreshock migration and repeating earthquakes;
- intermittent episodes of foreshocks without an accelerating pattern leading up to the mainshock.

[Zhu, et al., 2022]

On/Off-fault foreshocks

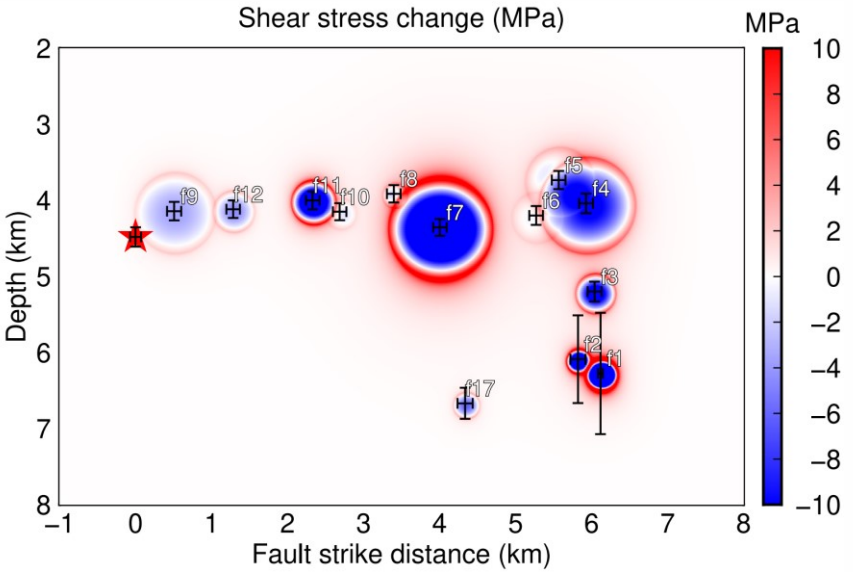
M>2.8 foreshock: focal mechanisms, rupture directivities
The black ones -> fault 1, the main rupture fault
The blue ones -> fault 2
The red ones -> fault 3, including the largest Mw5.2 foreshocks (f14)

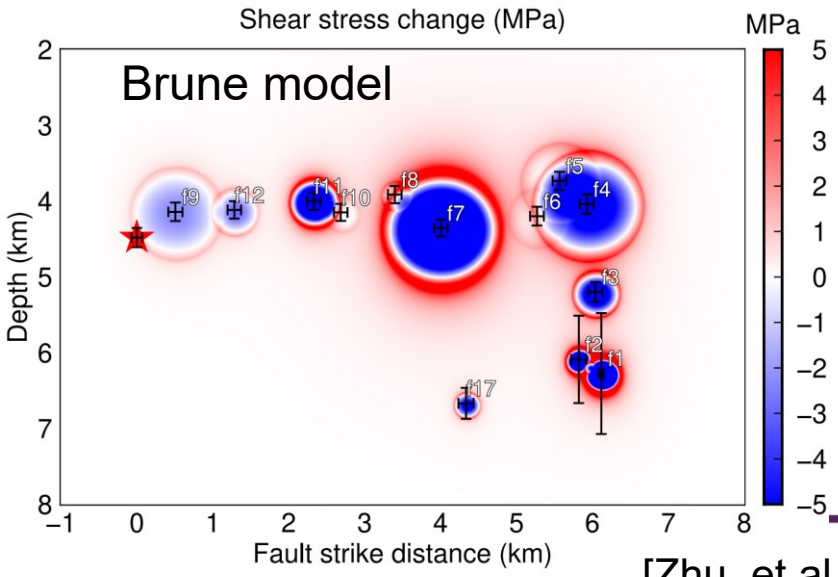


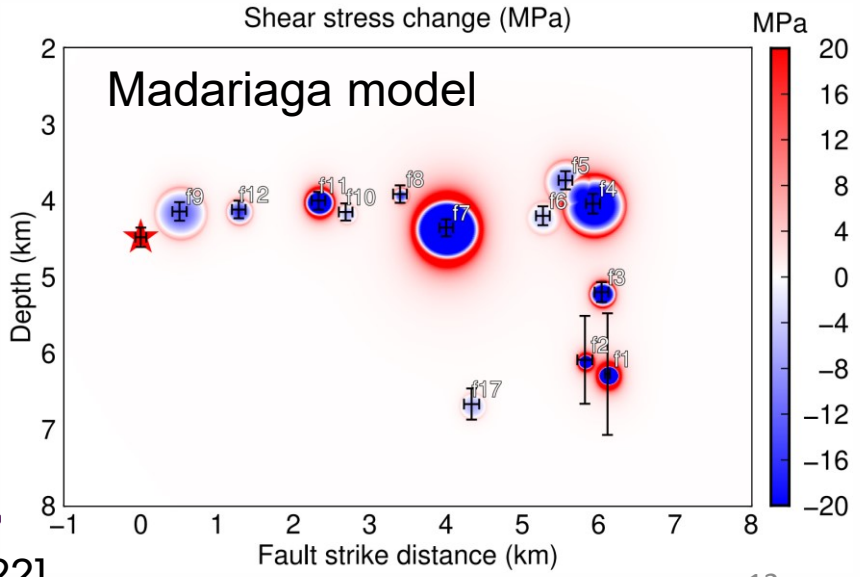
[Zhu, et al., 2022]

On-fault shear stress changes

- ruptured patches were adjacent to or only partially overlapped with each other
- mainshock nucleated at a location where previous foreshocks increased the shear stress by 0.26 Mpa (2.6 bar).
- It demonstrates a clear cascading failure process.





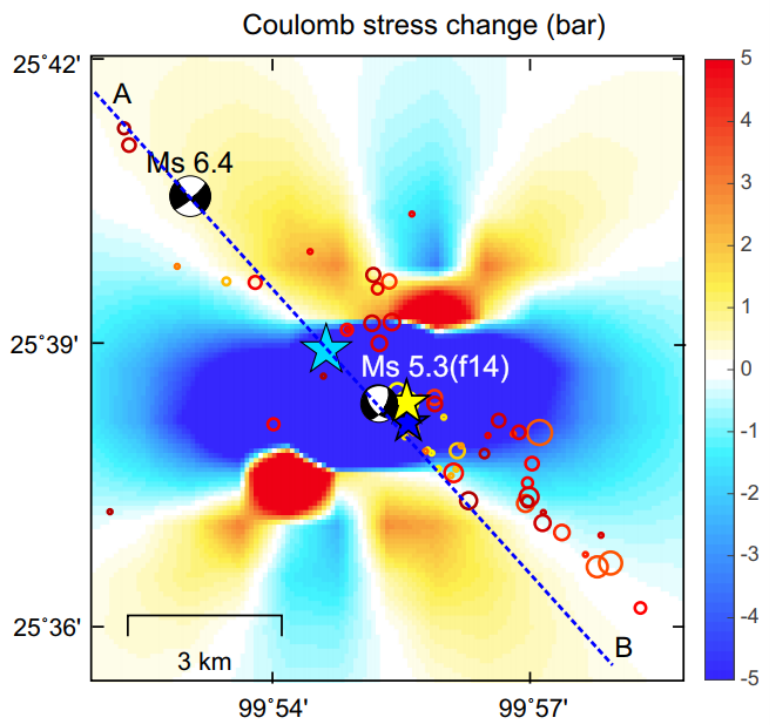


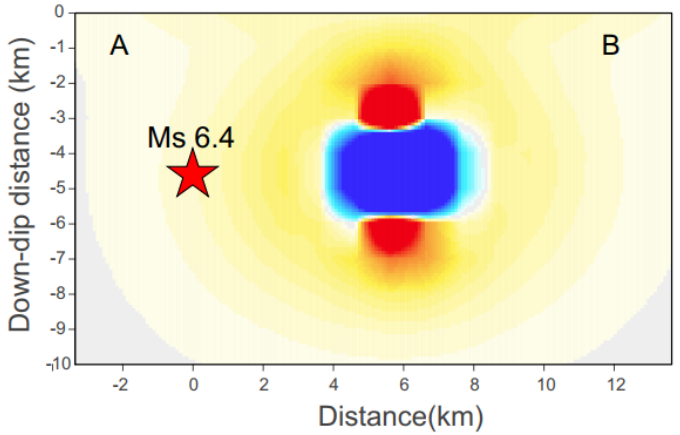
[Zhu, et al., 2022]

Increased CFS caused by the largest foreshock

The largest foreshock also increased the Coulomb stress at the mainshock focal location by 0.5 bar.

$$\Delta CFS = \Delta\tau + \mu\Delta\sigma$$





[Zhu, et al., 2022]

Summary

- Spatial and temporal evolution pattern of the foreshocks suggest a cascading mechanism

  (1) the lack of consistent foreshock migration and repeating earthquakes ;
  (2) intermittent episodes of foreshocks without an accelerating pattern leading up to the mainshock;
  (3) most of the large foreshocks abutted without overlap or with minor overlap and cumulatively increased the stress at the mainshock hypocenter.

- These foreshocks play critical roles in hazard mitigation

Thanks