Stanford | Stanford Center for Induced and Triggered Seismicity

School of Earth, Energy & Environmental Sciences

A Macroscopic Study of the Spatio-Temporal Evolution of Induced Seismicity Clusters in Oklahoma and Southern Kansas

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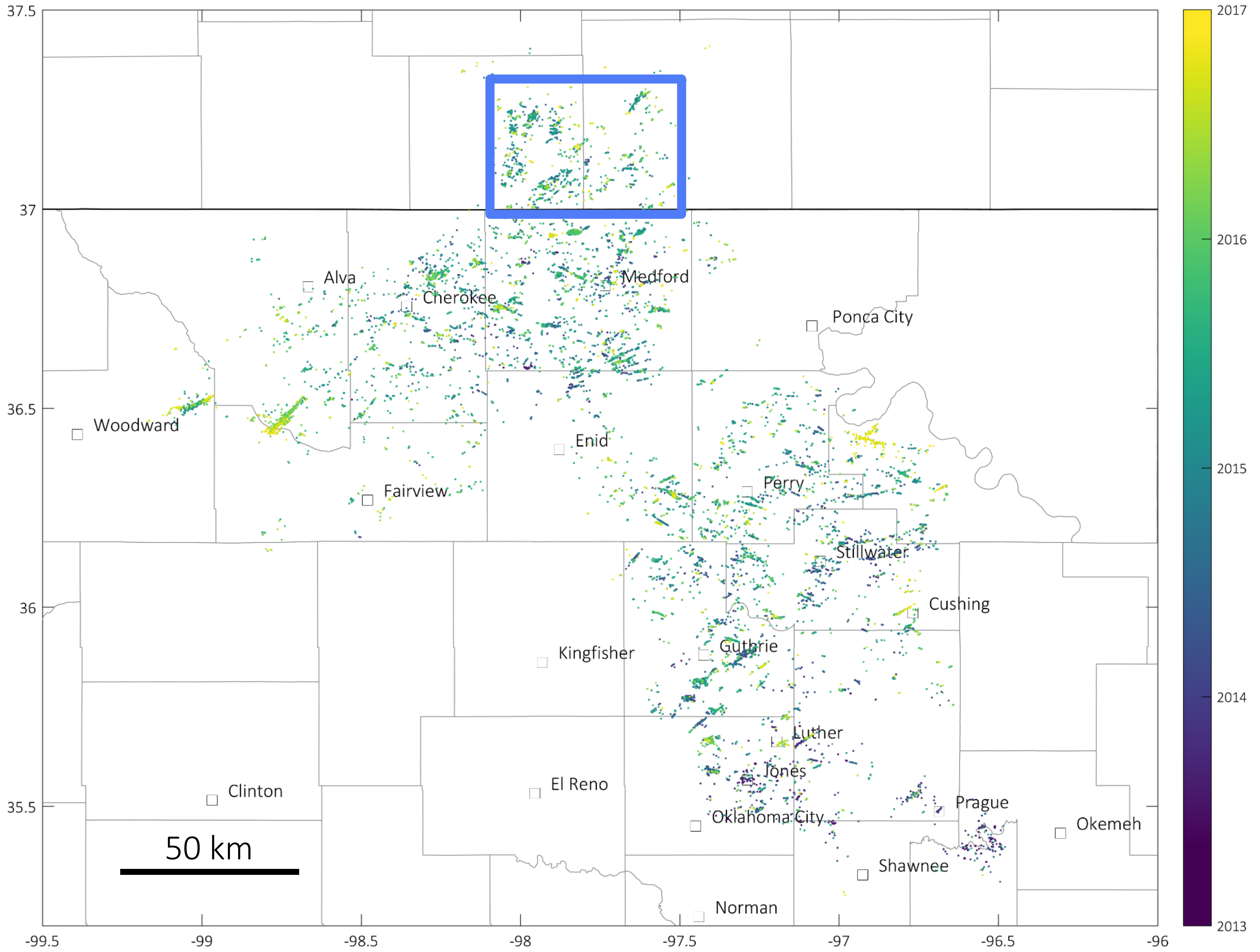
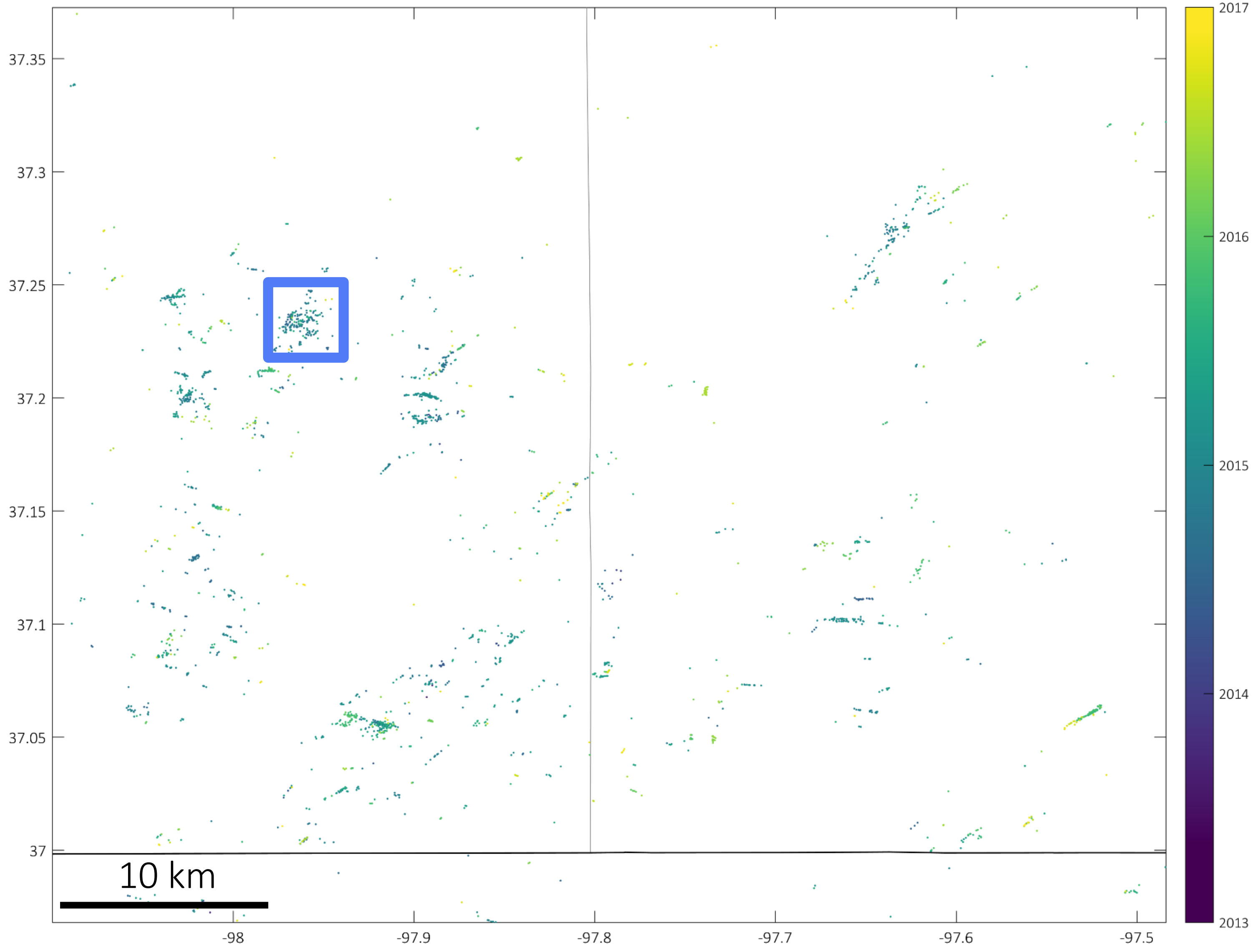
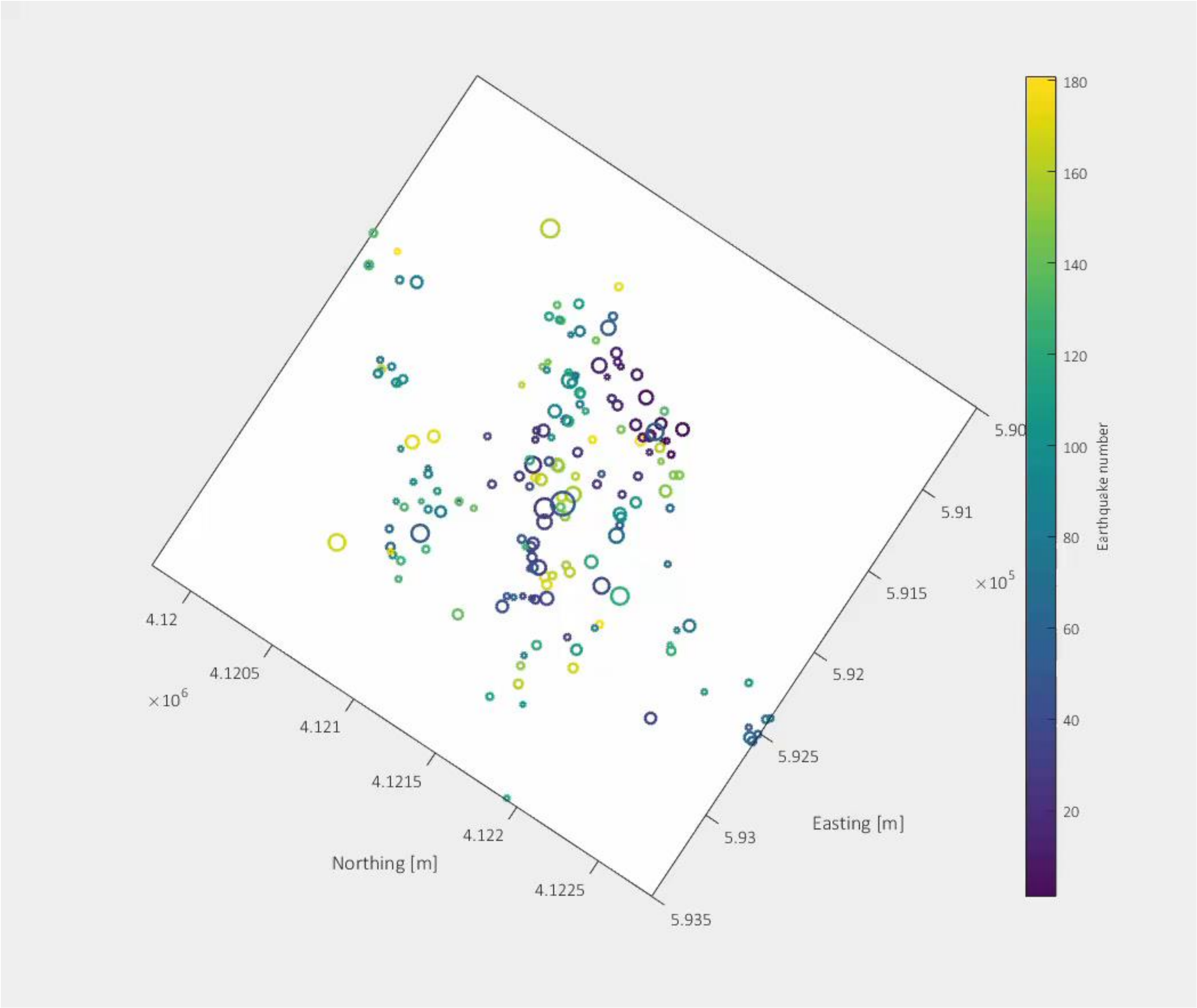
Relocated earthquakes May-2013 – November-2016



Relocated earthquakes May-2013 – November-2016

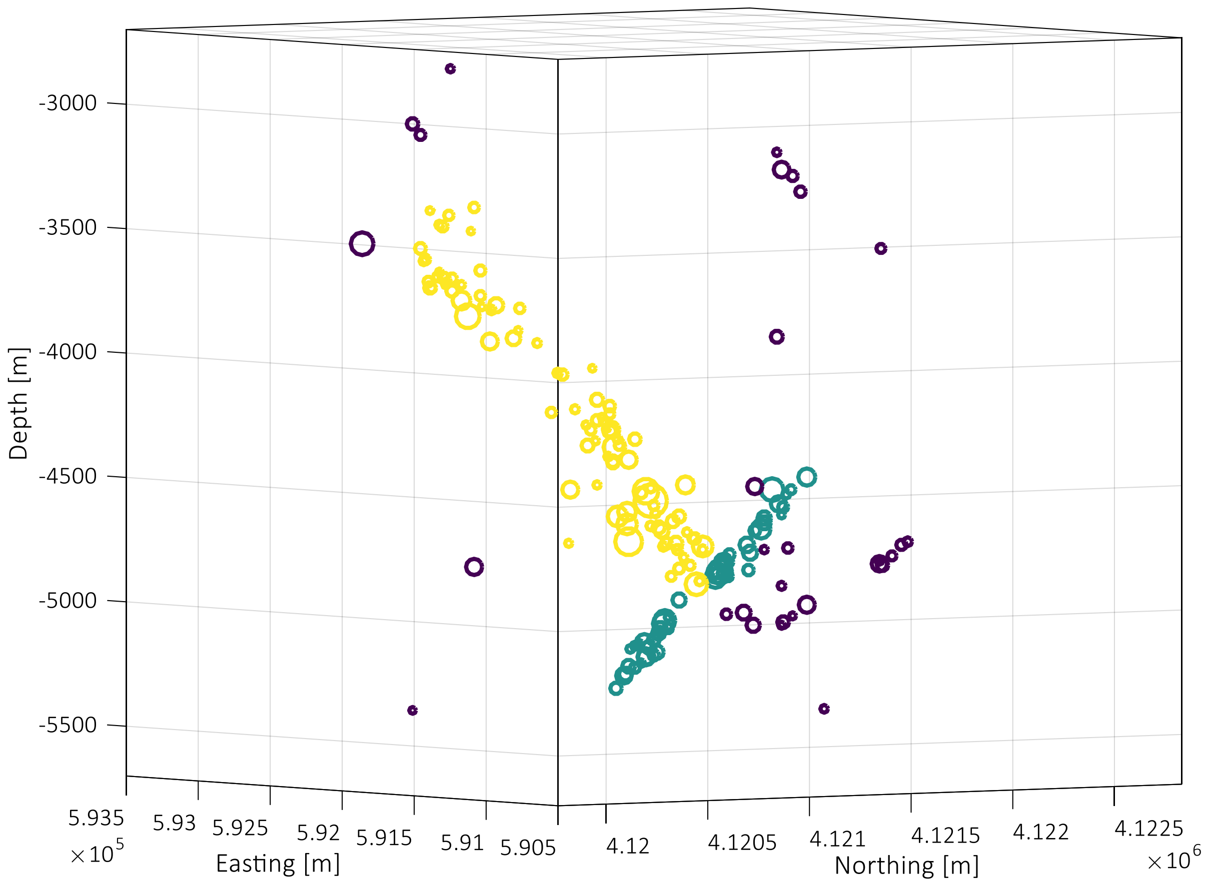


Harper cluster

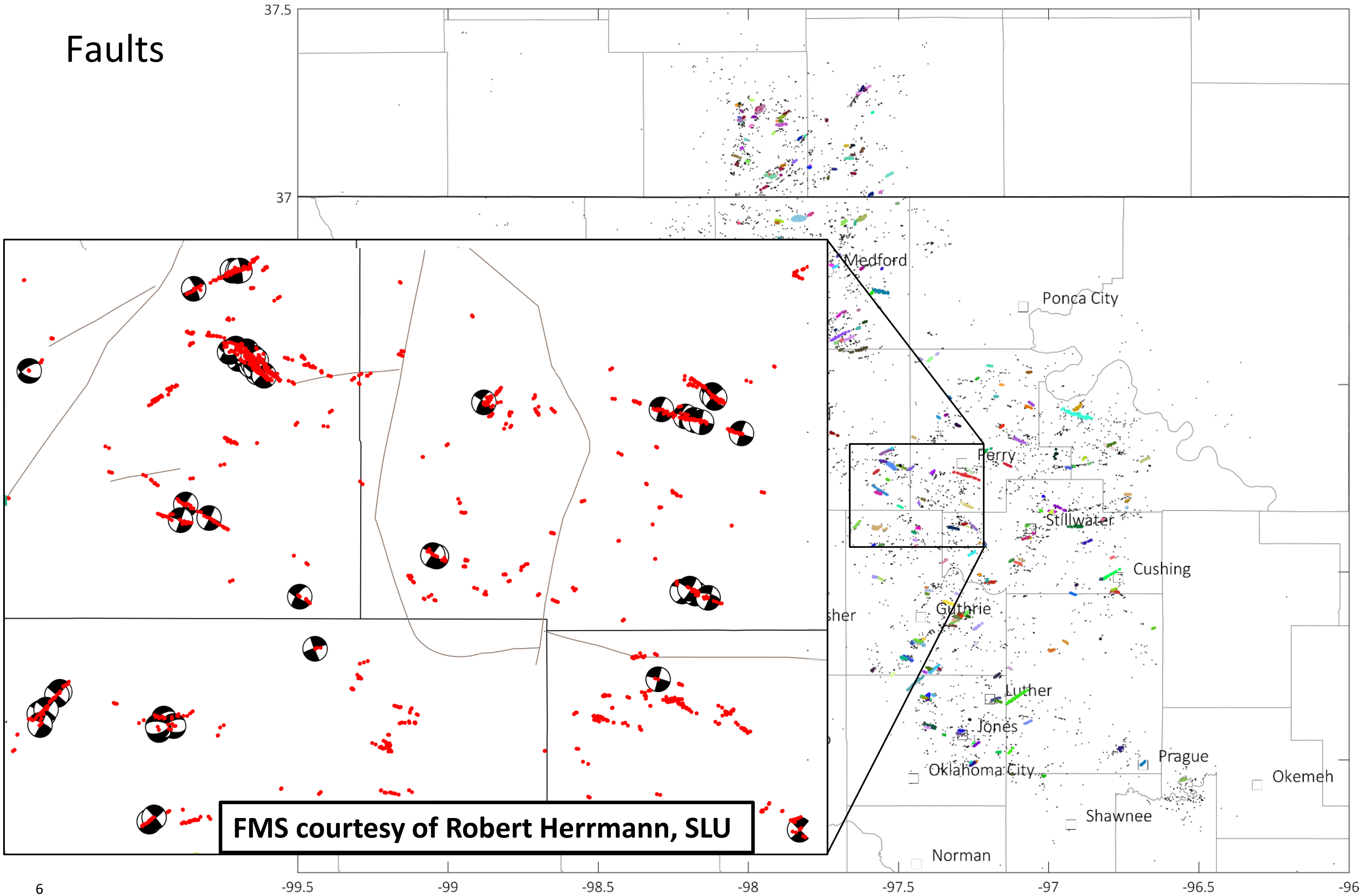


Cluster and fault identification

- Identify candidate clusters using DBSCAN algorithm
  - Recursively identify clusters (minPts = 10, r=700 m)
- Manually review clusters in 3-D view and subdivide into single faults
- Obtain strike and dip of fault planes from eigenvectors of empirical covariance matrix for each plane
- Strikes are usually very well constrained
- Quality of dip is dependent on the distance to nearest stations
  - For large DMIN earthquake depths of a cluster becomes vertically compressed during the relative relocation steps

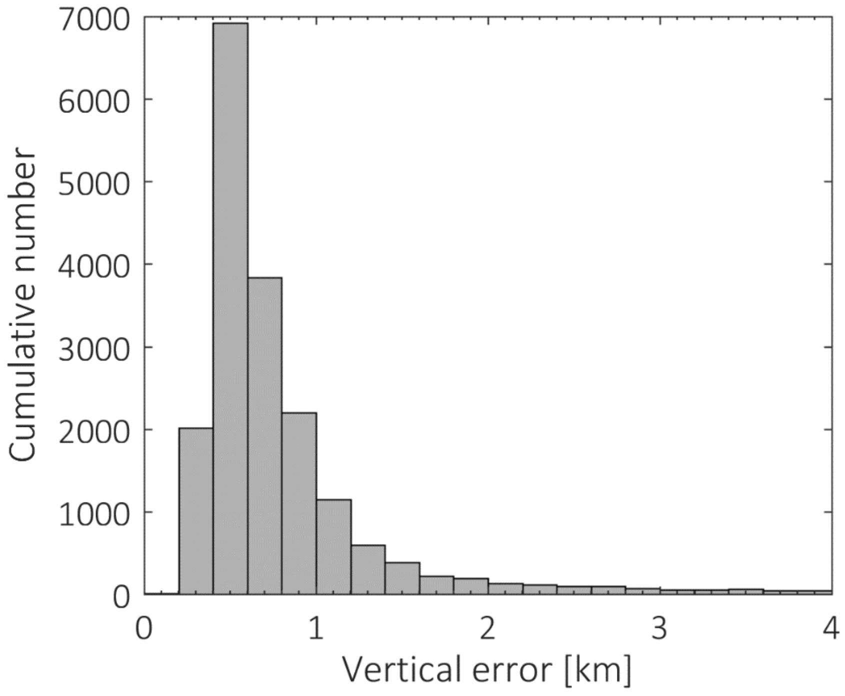


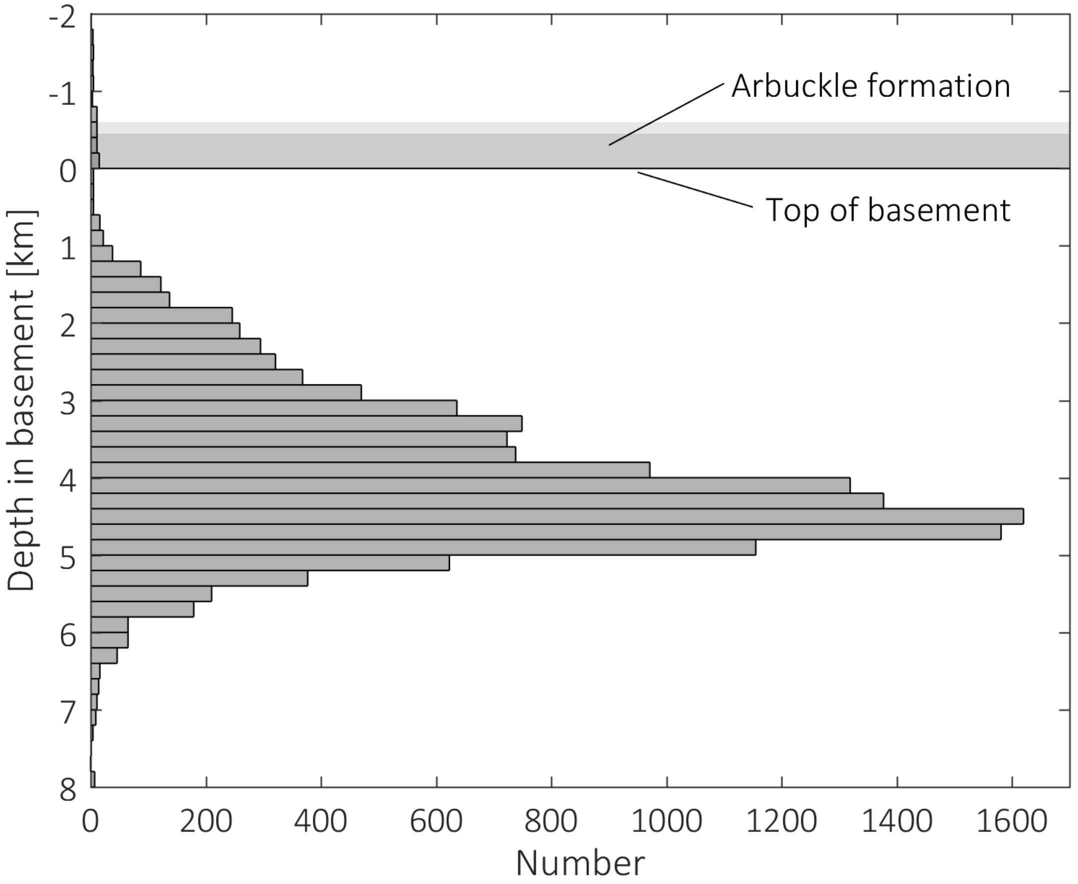
Faults



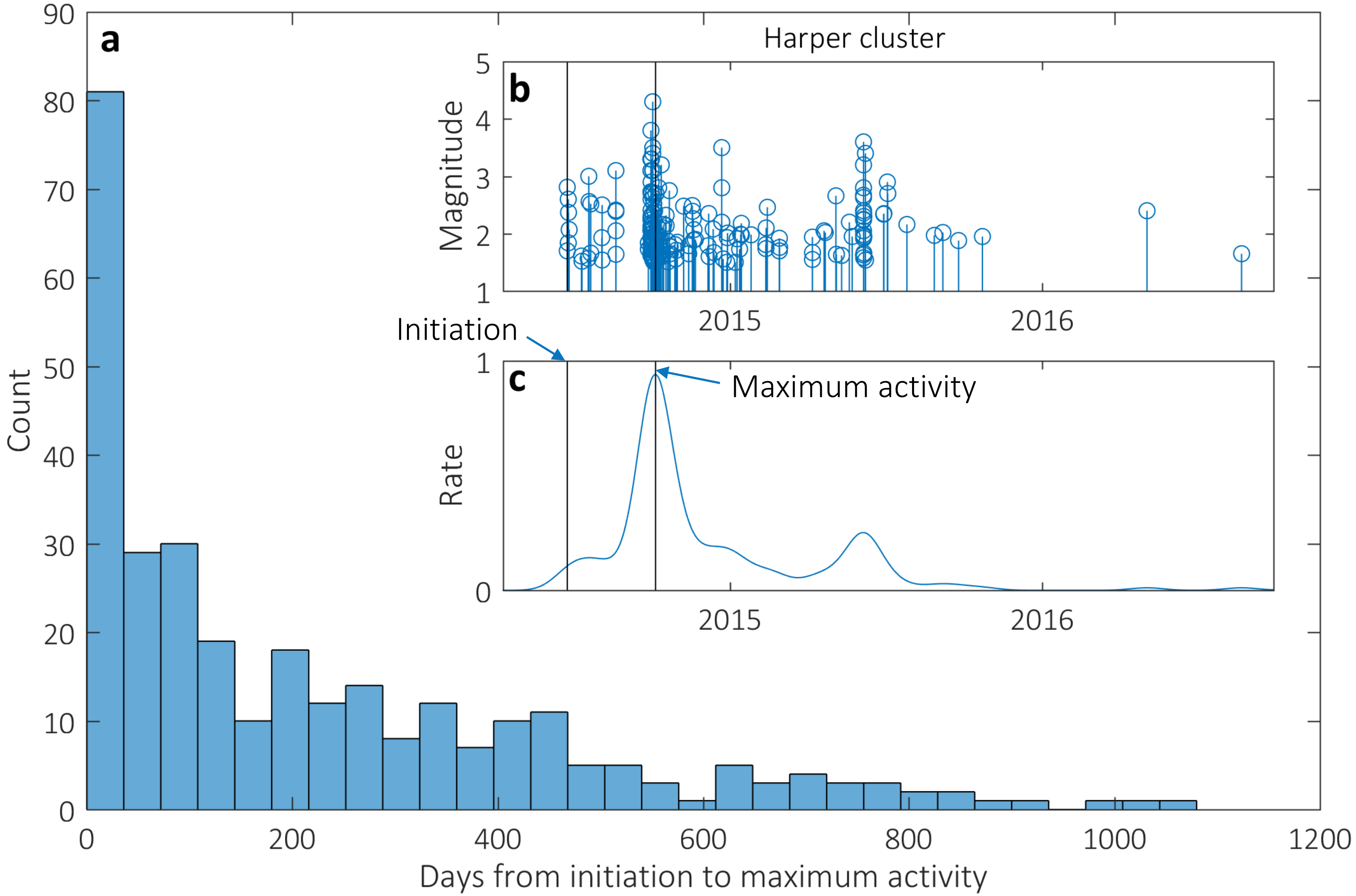
37.5
37
Medford
Ponca City
Perry
Stillwater
Cushing
Guthrie
Luther
Jones
Prague
Okemeh
Oklahoma City
Shawnee
Norman
-99.5
-99
-98.5
-98
-97.5
-97
-96.5
-96
FMS courtesy of Robert Herrmann, SLU

Depth distribution





Clusters often initiate much earlier than peak activity

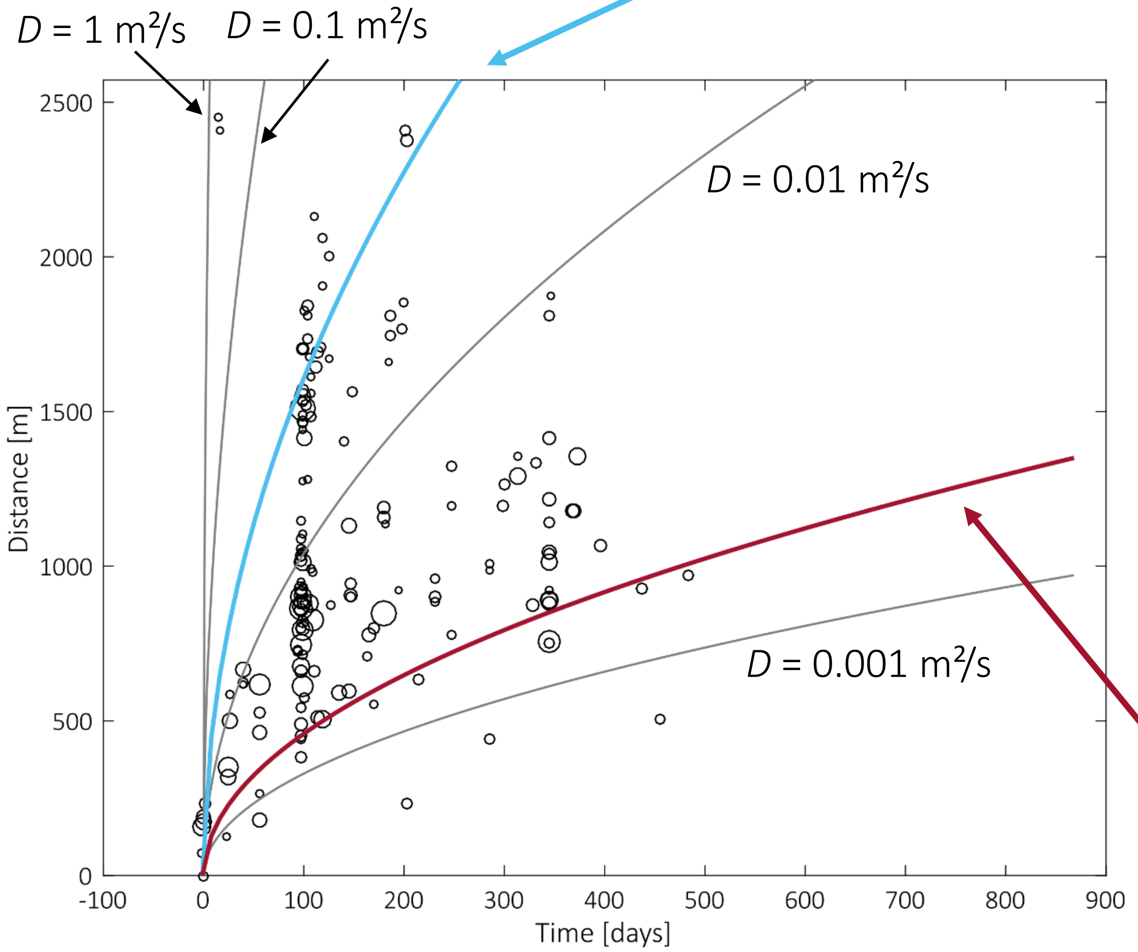


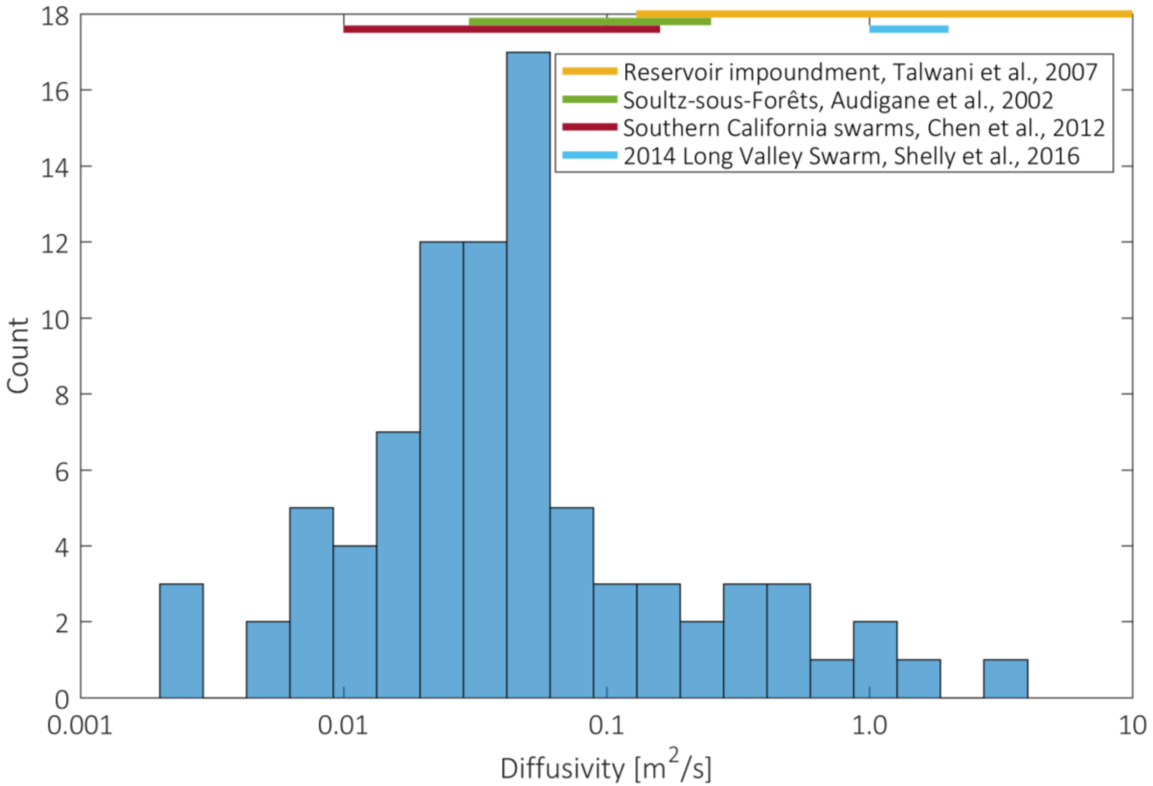
Diffusive fronts

Triggering front:

1. Remove temporal outliers at beginning (none here)
2. Try events as the origin (*x, y, z, t*) such that 90% of events are below $\sqrt{4\pi Dt}$ envelope, minimize *D*.

- Estimate of *D* is biased towards the initial phase of sequence





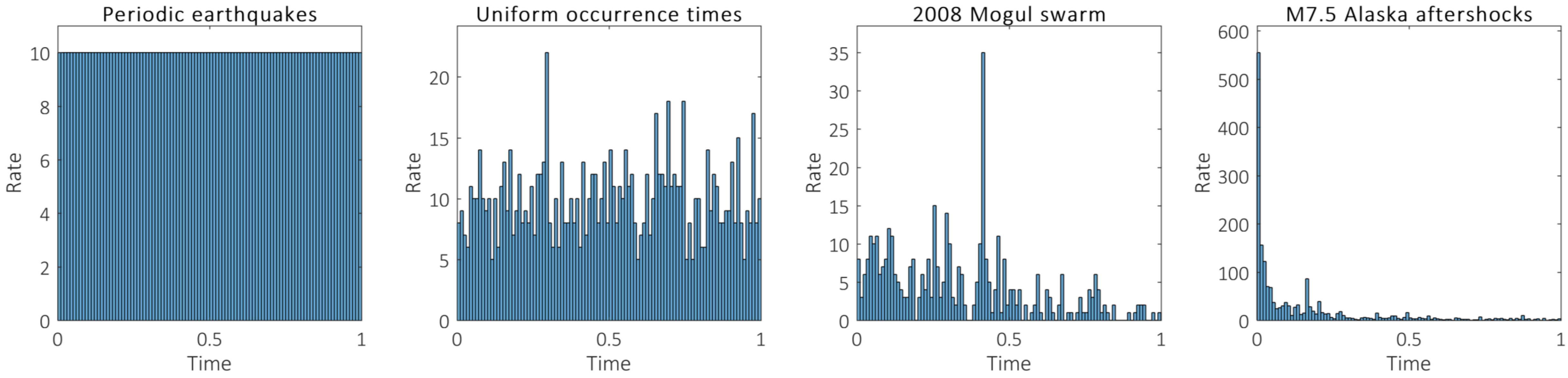
Back front:

1. Take same origin (*x, y, z, t*) as for triggering front
2. Fit in reverse (largest *D* with 90% of events above)

- Relaxation process, D_{back} ~ 0.01 D_{trig}

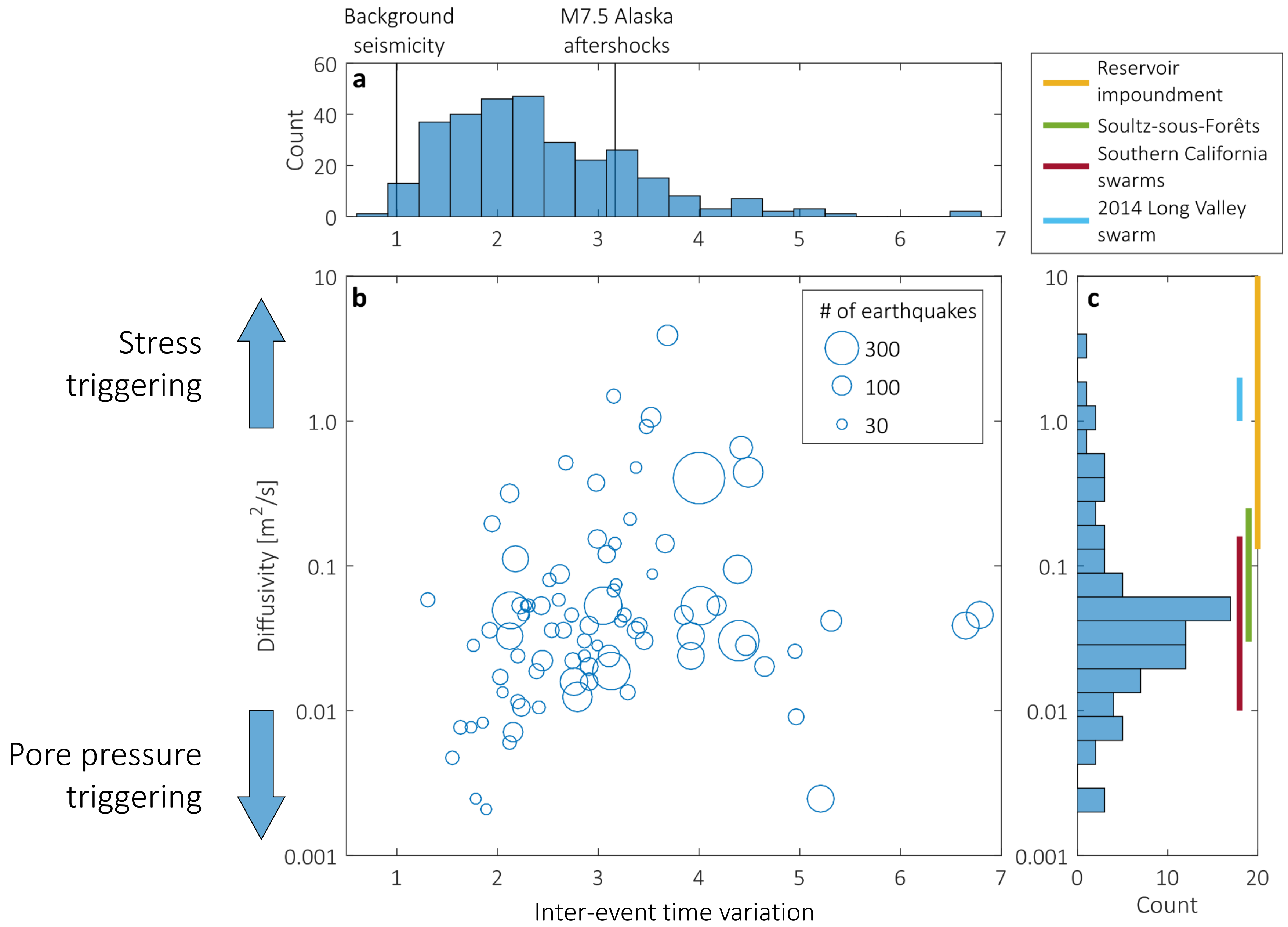
Episodicity defined using inter-event time distribution

- Use inter-event time statistics to quantify the temporal clustering
- Coefficient of variation $c_v(\tau) = \sigma(\tau)/\bar{\tau}$, with inter-event times τ



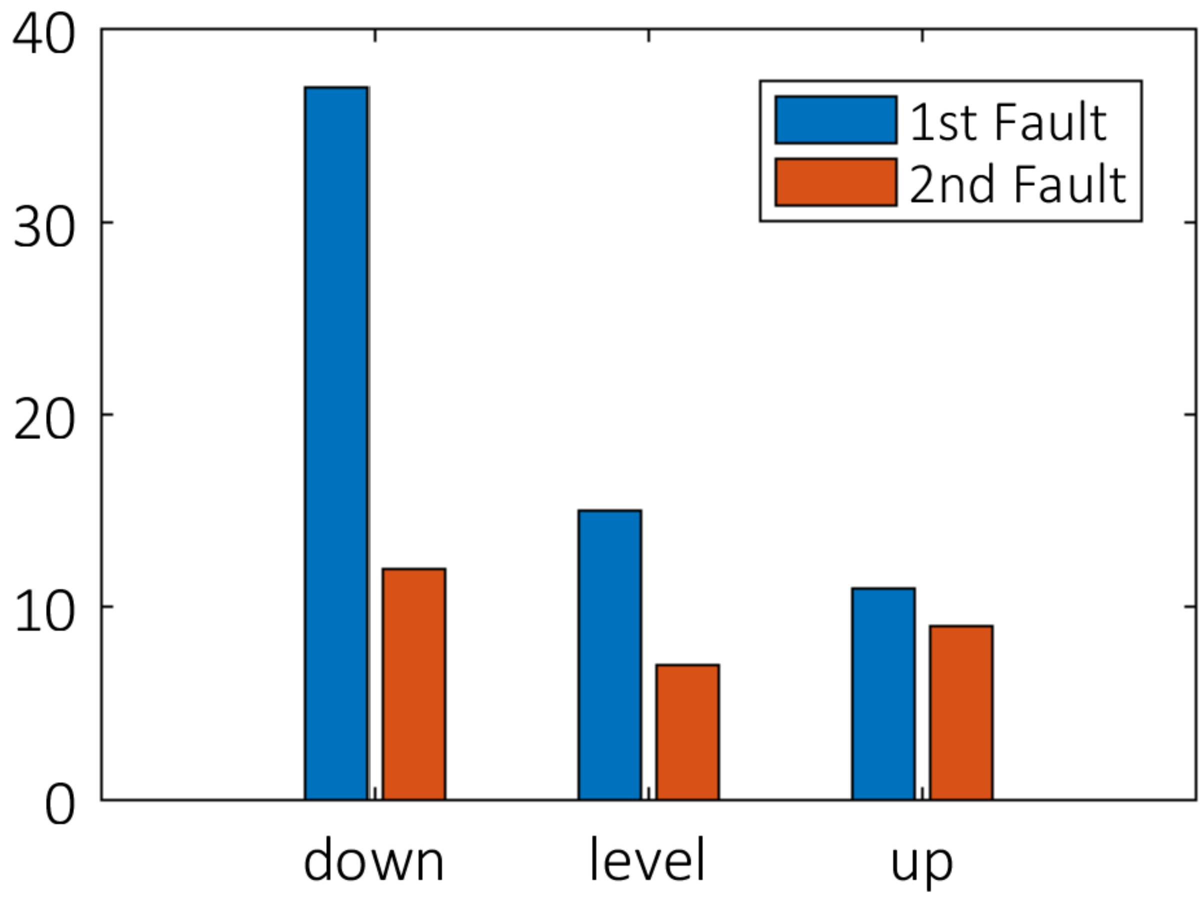
$c_v = 0.0$ $c_v = 0.96$ $c_v = 1.9$ $c_v = 3.3$

Apparent diffusivity vs. Sequence episodicity

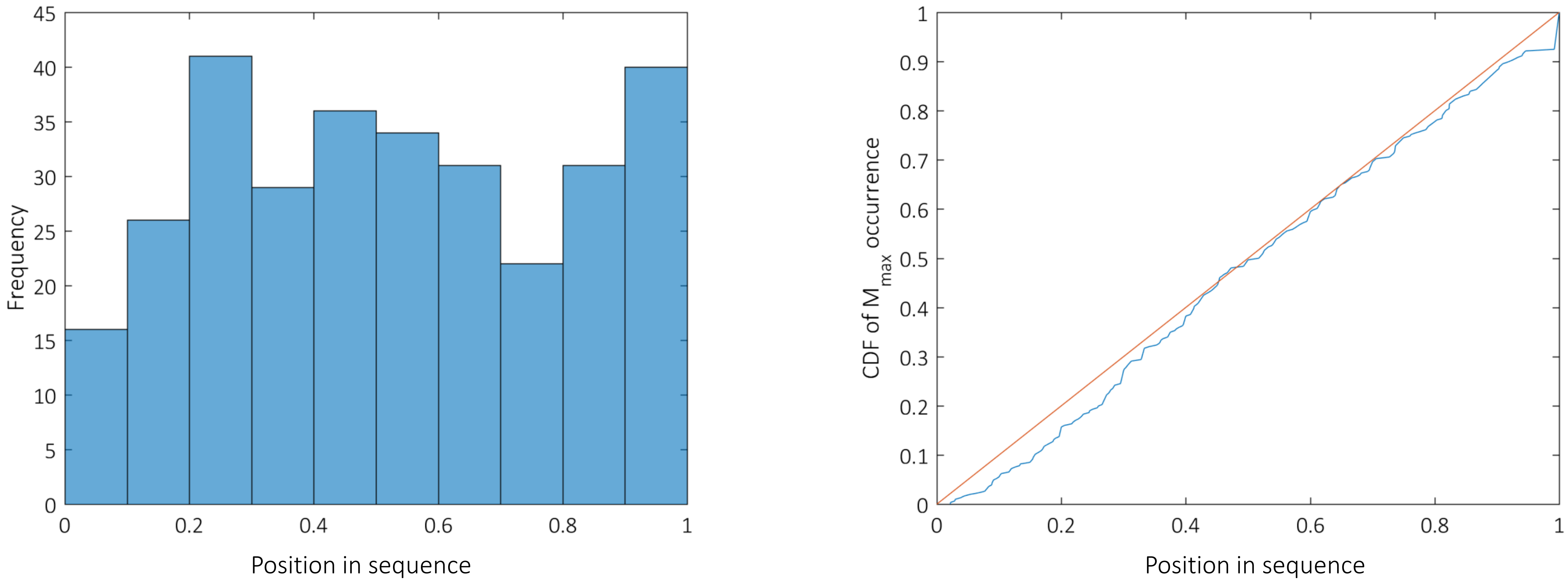


Cluster vertical migration

- Manual interpretation by faults in order of activation
- 63 clusters with > 50 events analyzed



Position of largest event in clusters



The position of M_{max} in a cluster is random but less likely at the beginning

Key observations

1. Seismicity occurs in distinct clusters that may span several faults
2. Sequences occur typically at 4 km below top of basement
3. No cluster starts with the largest earthquake and many clusters initiate months before peak activity
4. Apparent diffusivity correlates with episodicity
(burst-like sequences propagate through faster stress transfer, swarm-like sequences propagate through slower pore pressure diffusion)
5. Majority of clusters show activity migrating downward (driving source is above)
6. The position of M_{max} in a cluster is random, but not at the beginning

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Thank you!

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