Direct fault states assessment from wavefield properties: application to the 2009 L'Aquila earthquake

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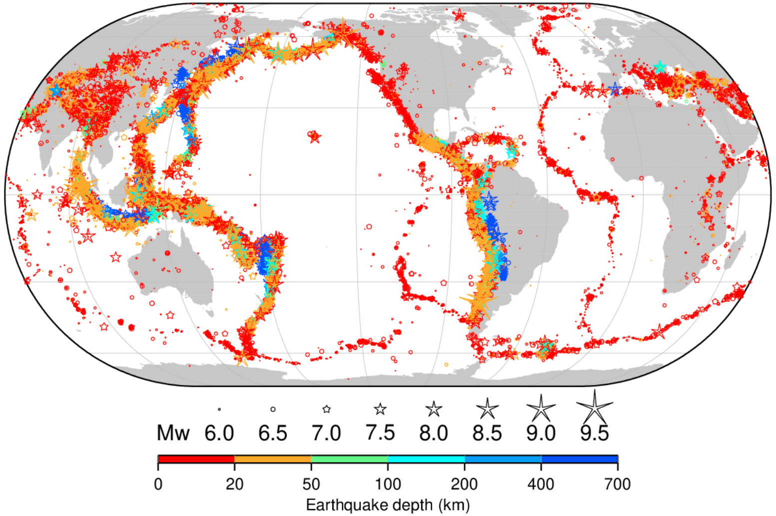
Backgrounds   Go beyond the catalog

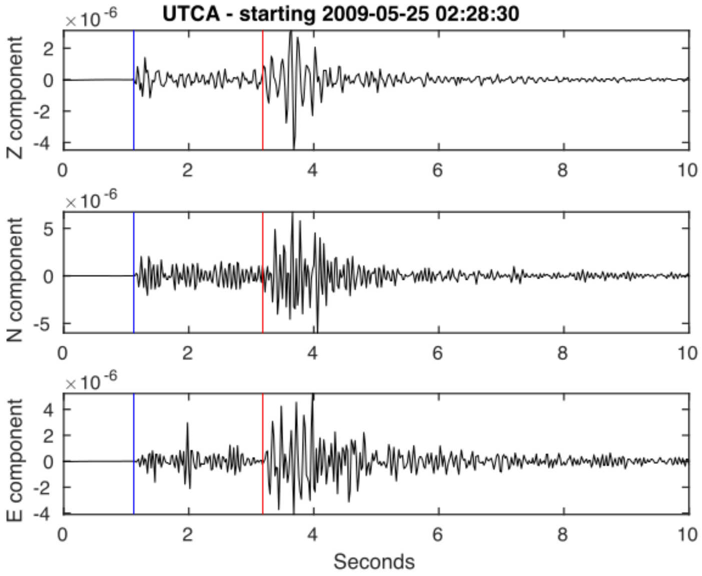


ISC-GEM Catalogue

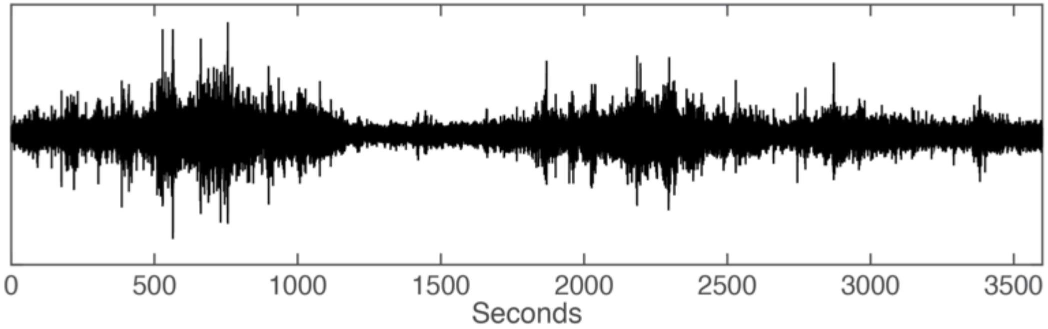
Seismic catalog is pervasively used for studying earthquake and fault physics.

Seismic catalogs are currently the main way of labeling seismic data.

In continuous seismic data, there may be signals that cannot be easily included into a seismic catalog.

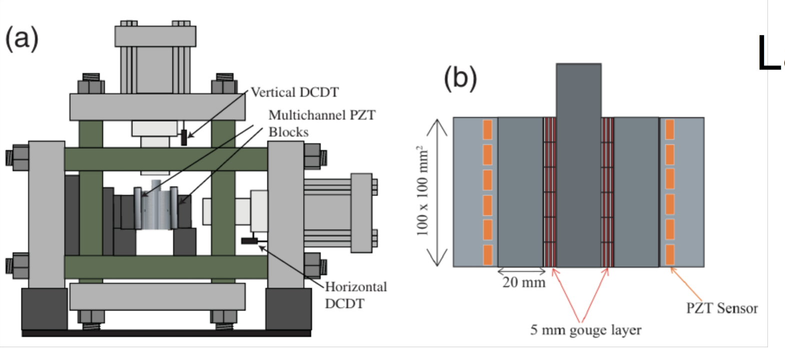


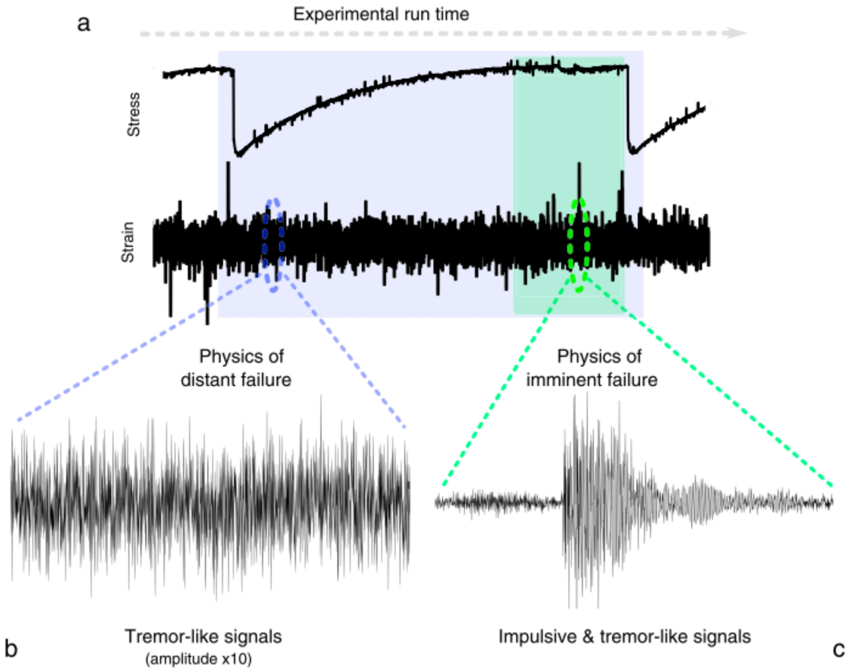
Tremors, slow-earthquakes, anomalous signals, ...



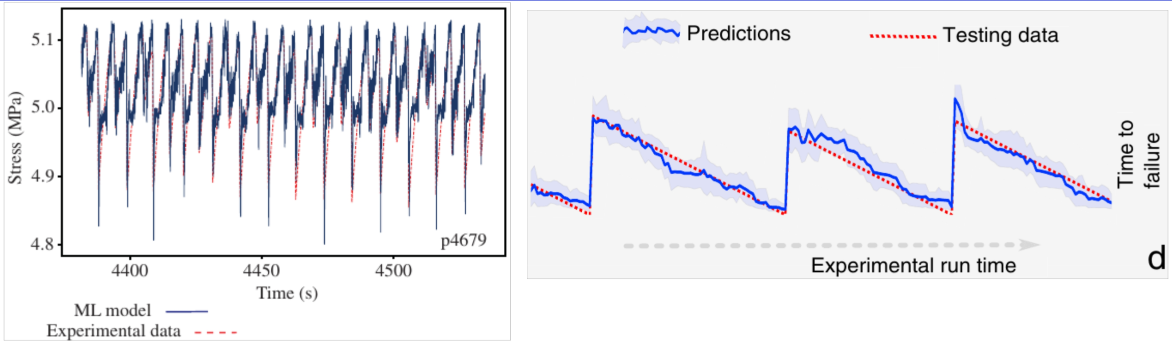
Continuous seismic data contain much more information about fault physics than what is actually employed.

Introduction: utilize continuous wavefield (laboratory experiments)

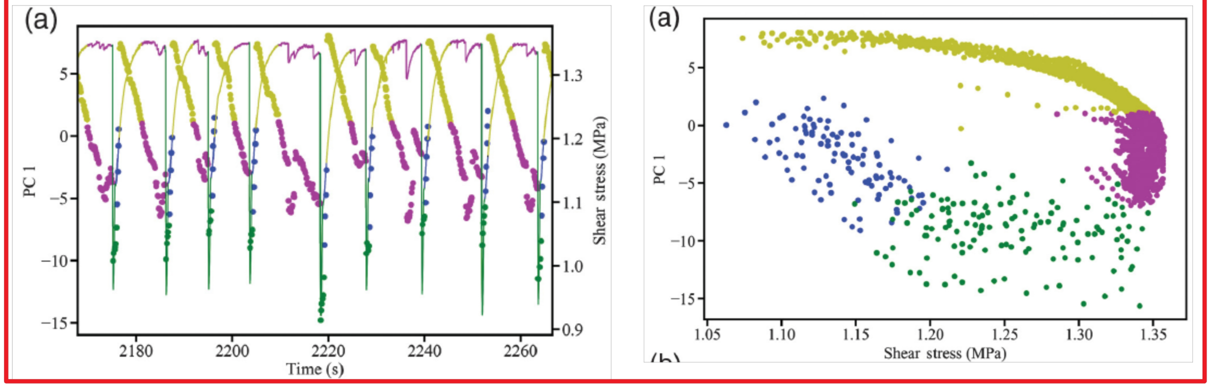




Laboratory experiments to simulate earthquakes in the Lab.



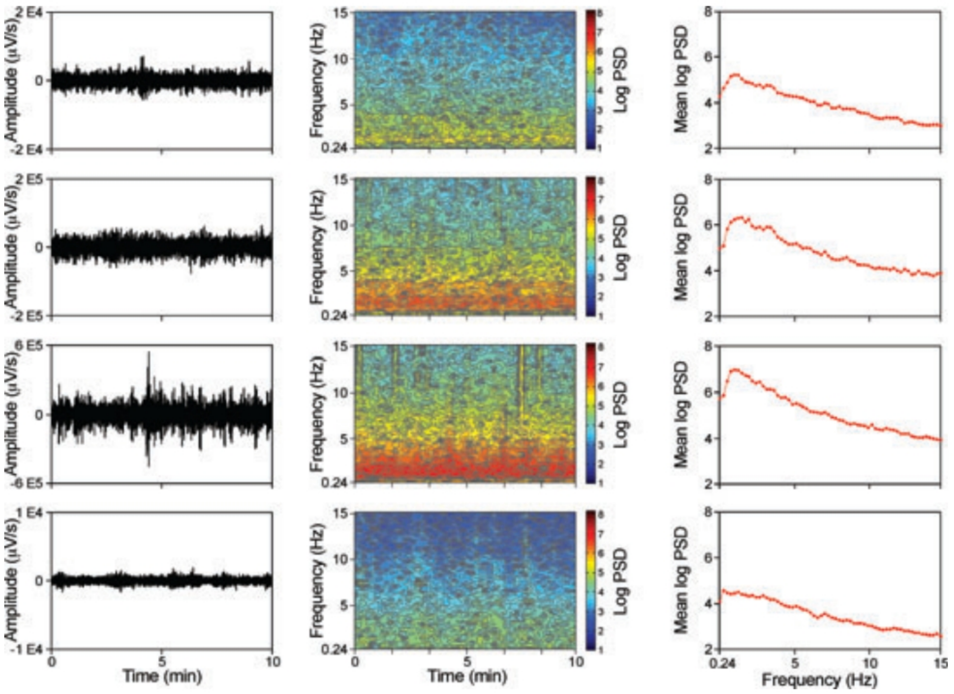
Supervised machine learning to predict failure times



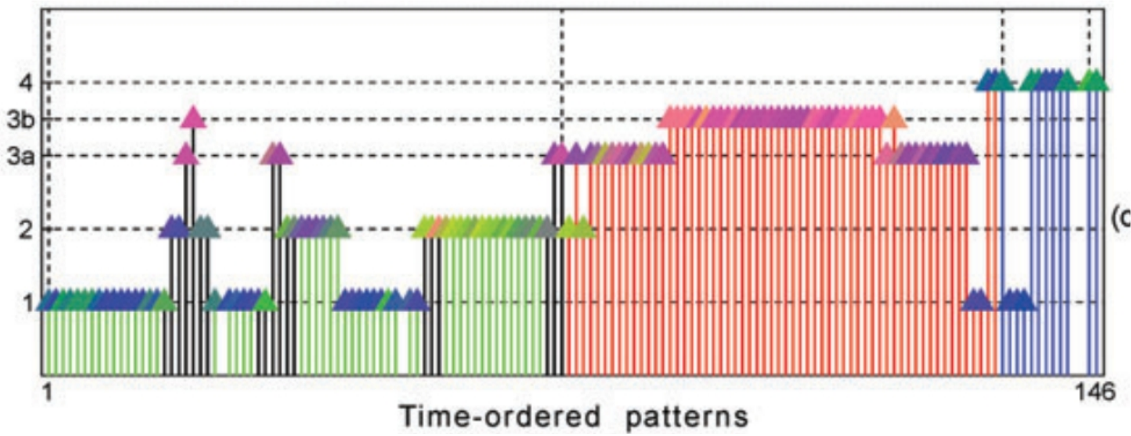
Unsupervised machine learning to identify patterns in AEs

Bertrand Rouet-Leduc et al. 2017; David C. Bolton et al. 2019

Introduction: utilize continuous wavefield (volcano settings)



time-series spectrograms feature vector



unsupervised pattern classification

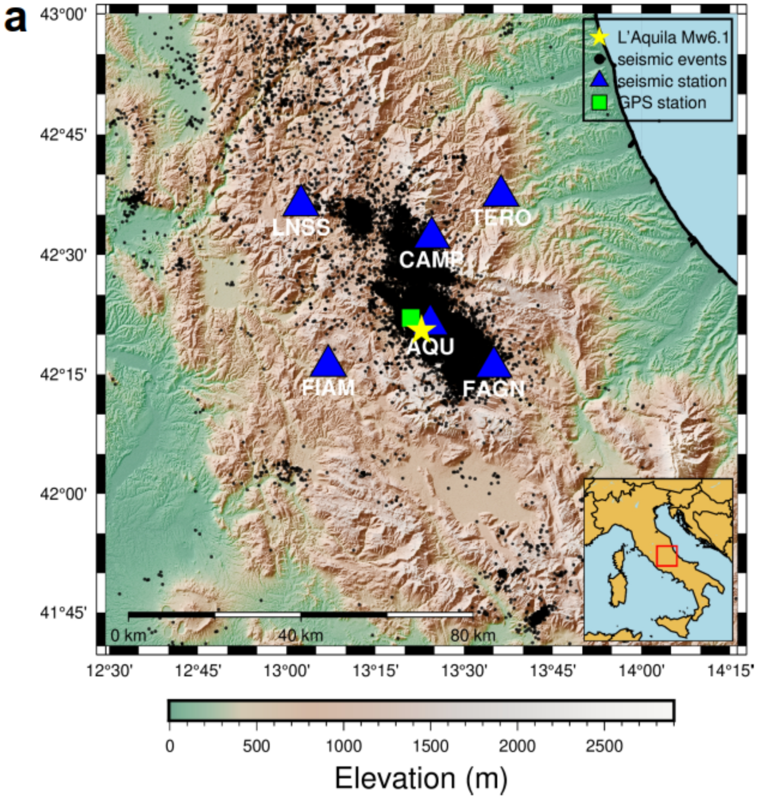
Through analyzing continuous data, one is able to identify the regimes of volcanic activity in an automatic way, which is of importance to volcano monitoring.

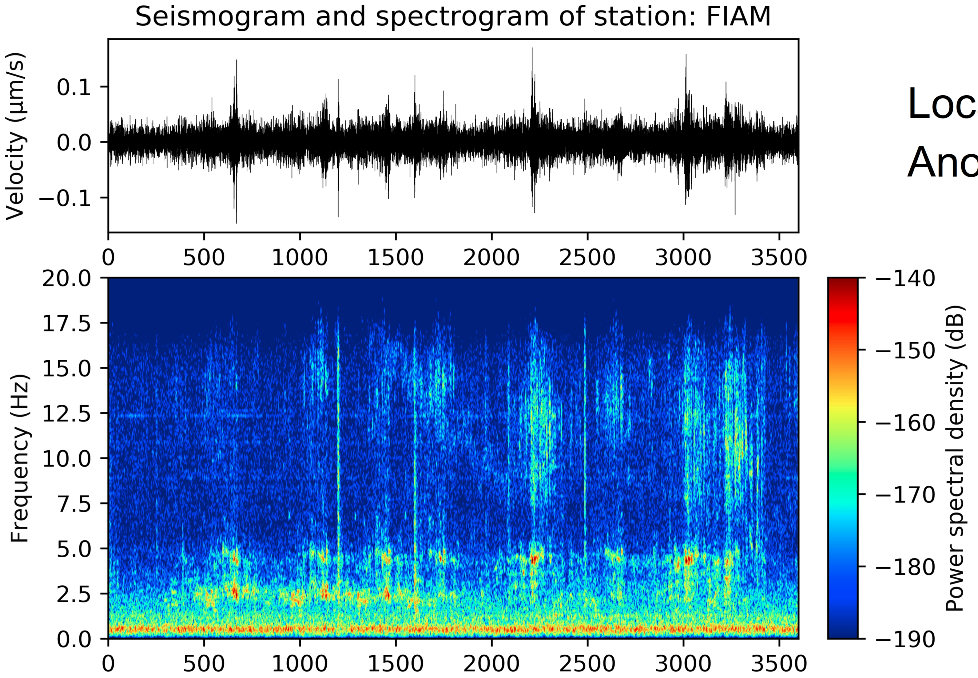
Different volcanic activities, e.g. **pre-eruption**, **lava fountains**, **eruption** and **post-eruption**, show seismic wavefield of distinct characteristics (especially in frequency content).

How about **earthquakes** and **faults**?

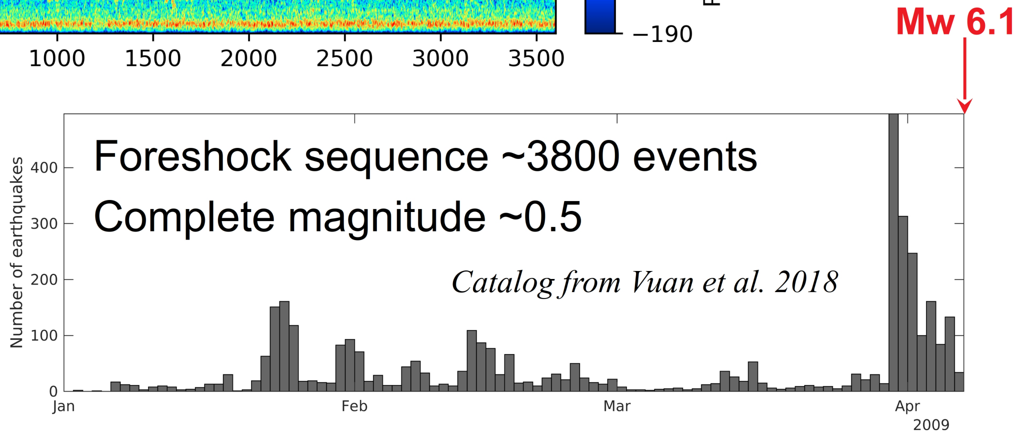
Langer et al., 2009

Introduction: utilize continuous wavefield (faults and earthquakes)





Local earthquakes;
Anomalous signals

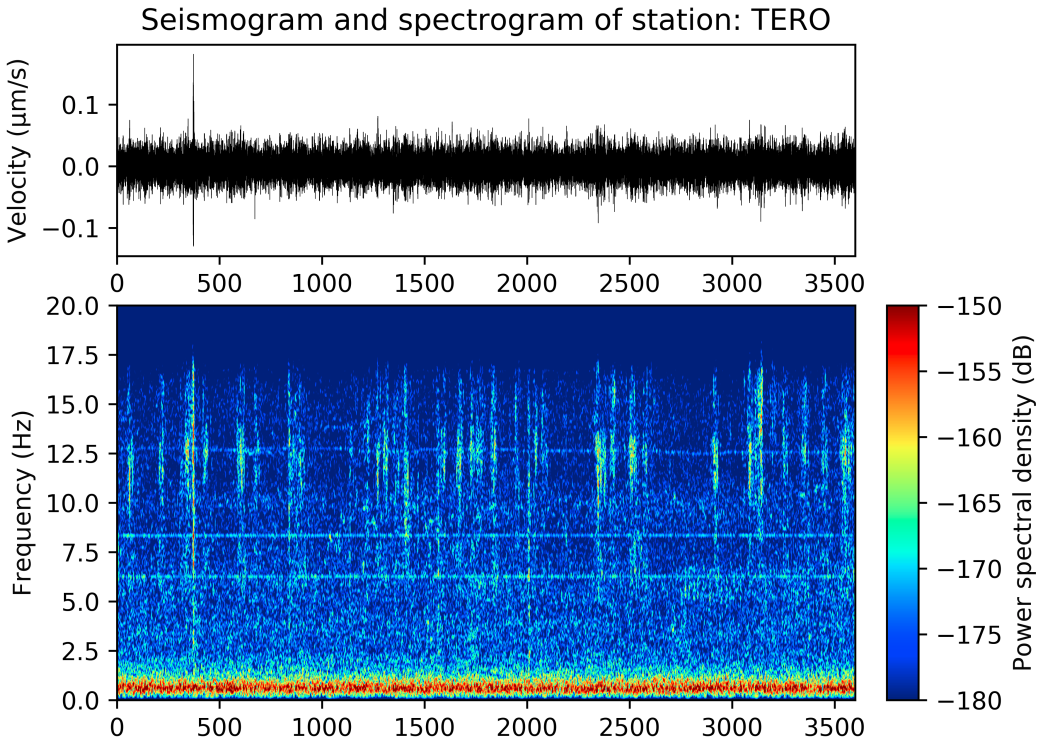


Foreshock sequence ~3800 events
Complete magnitude ~0.5

Catalog from Vuan et al. 2018

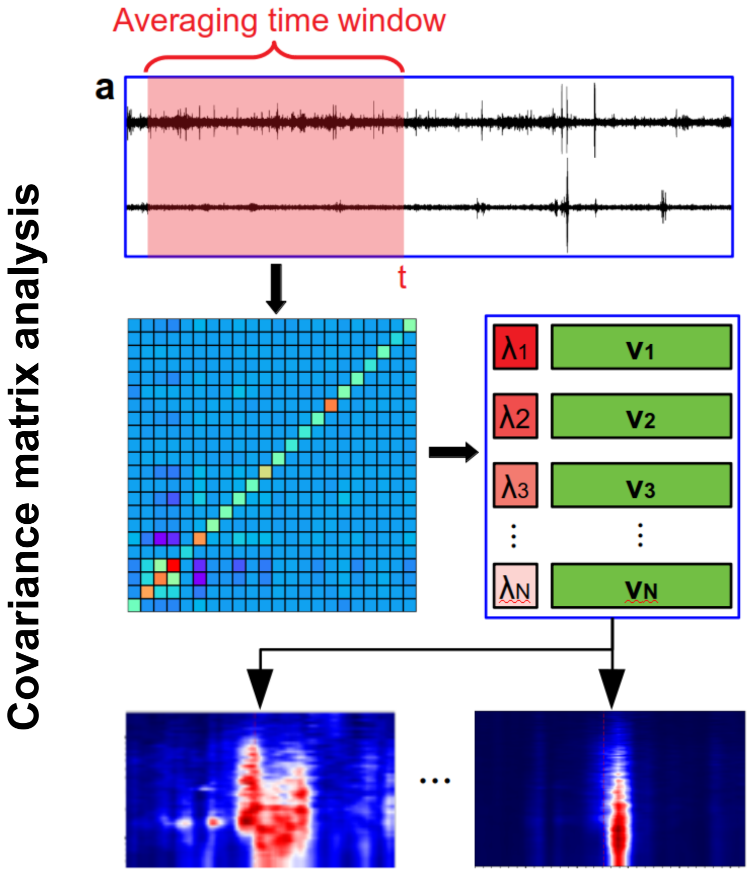
L'Aquila region: well instrumented area
+ complex faulting processes

Method: extract wavefield properties/features



Signals are easier to recognize in the frequency domain.

Seydoux et. al. 2016



- Features extracted based on seismic arrays;
- Analyzed in frequency domain;
- Factorization separates independent sources;

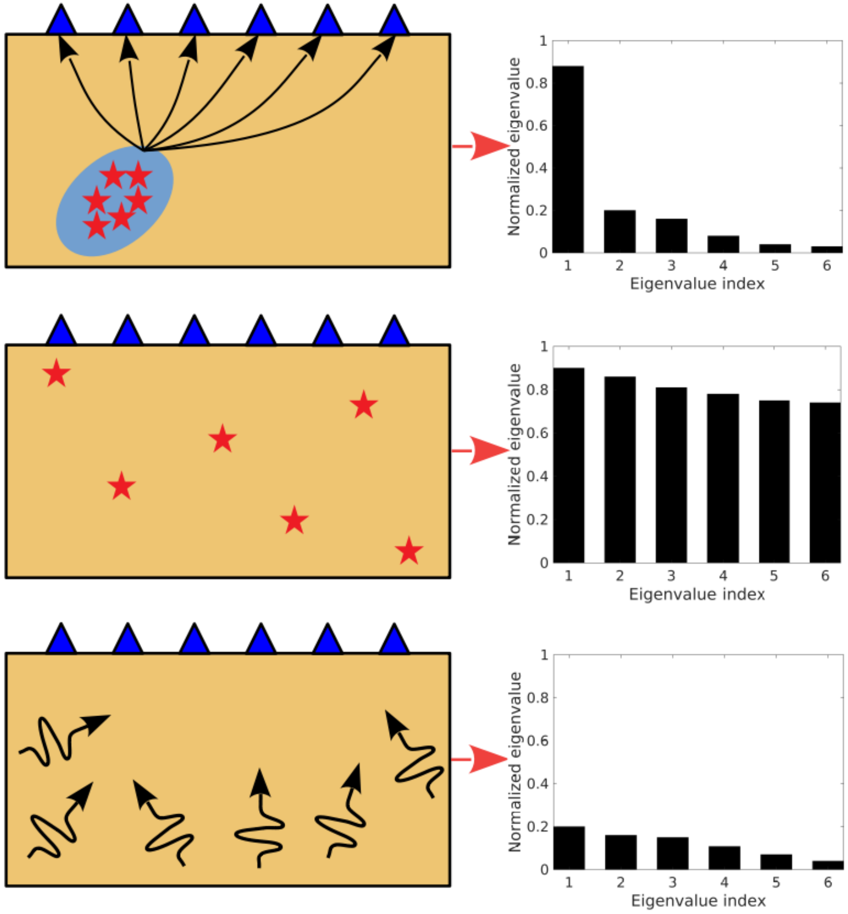
Method: extract wavefield properties/features

Wavefield features are extracted in a long-term averaging window of 60 days.

Wavefield coherence
- **Coherency**
- **Entropy**
- **Spectral-width**

Wavefield energy → **First-eigenvalue**

Coherence & energy → **Source variance**

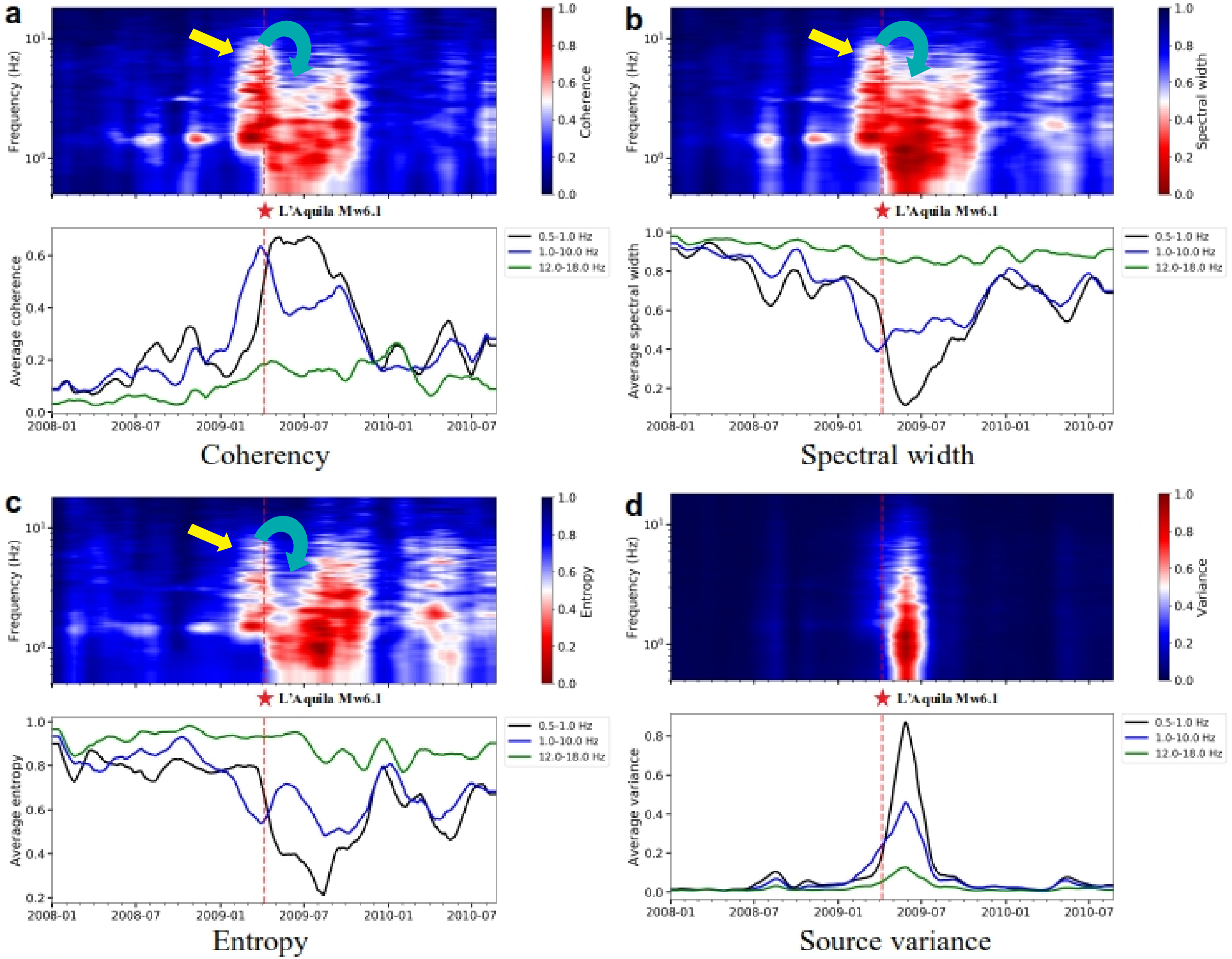


Localized sources
- High coherence
- High energy

Scattered sources
- Low coherence
- High energy

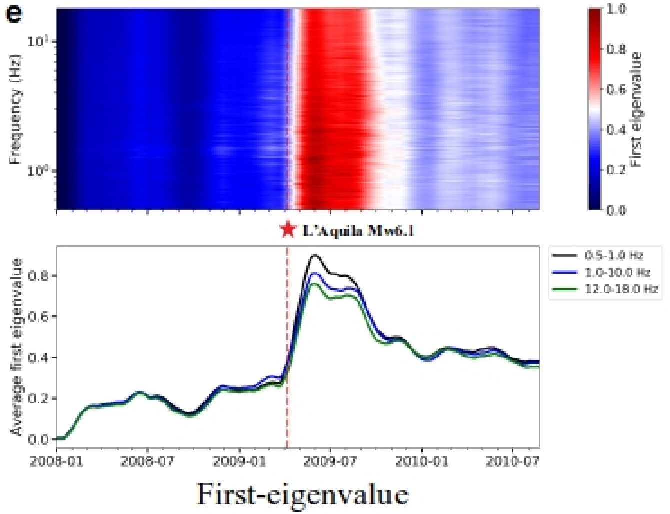
Noise sources
- Low coherence
- Low energy

Results: wavefield properties/features

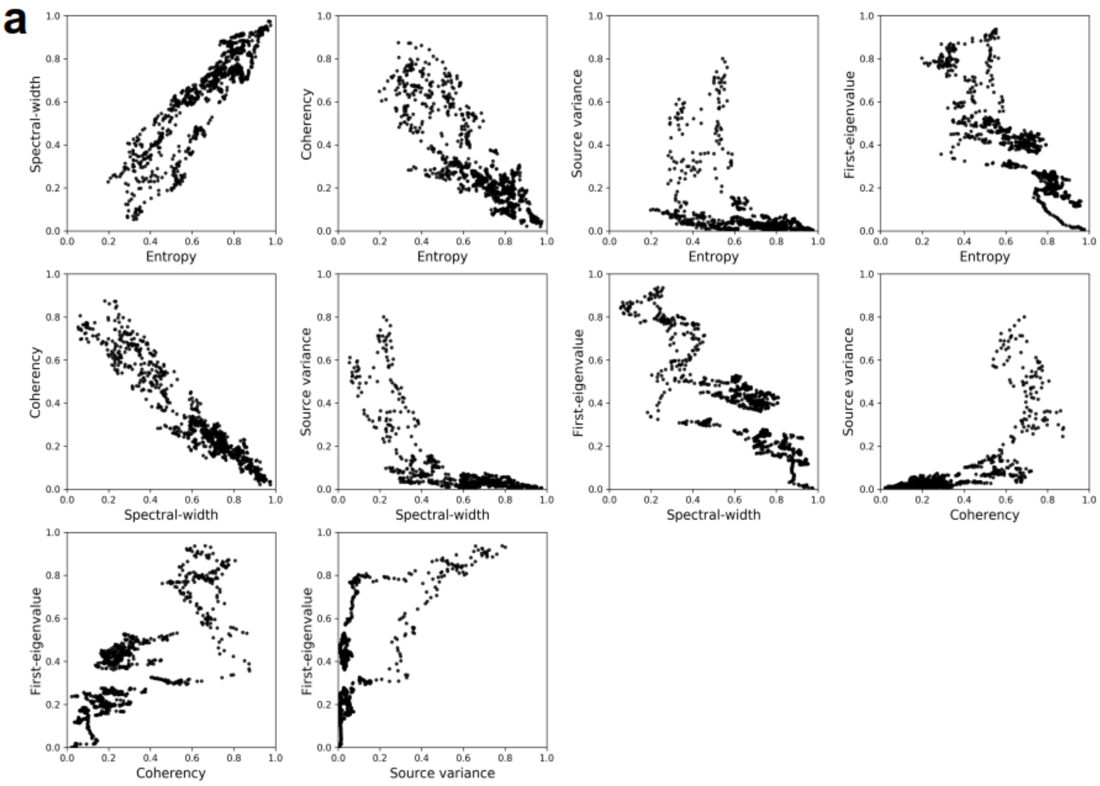


Coherence-based wavefield features reveal the preparation phase of the earthquake.

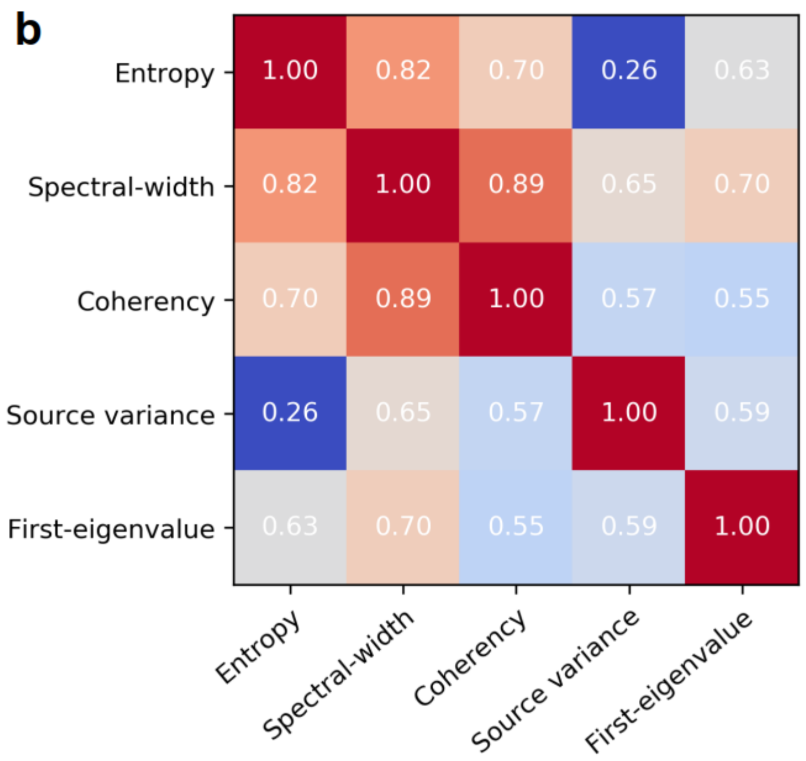
Use unsupervised analysis to discern the temporal evolution of the wavefield and fault states.



Results: correlation analysis between features

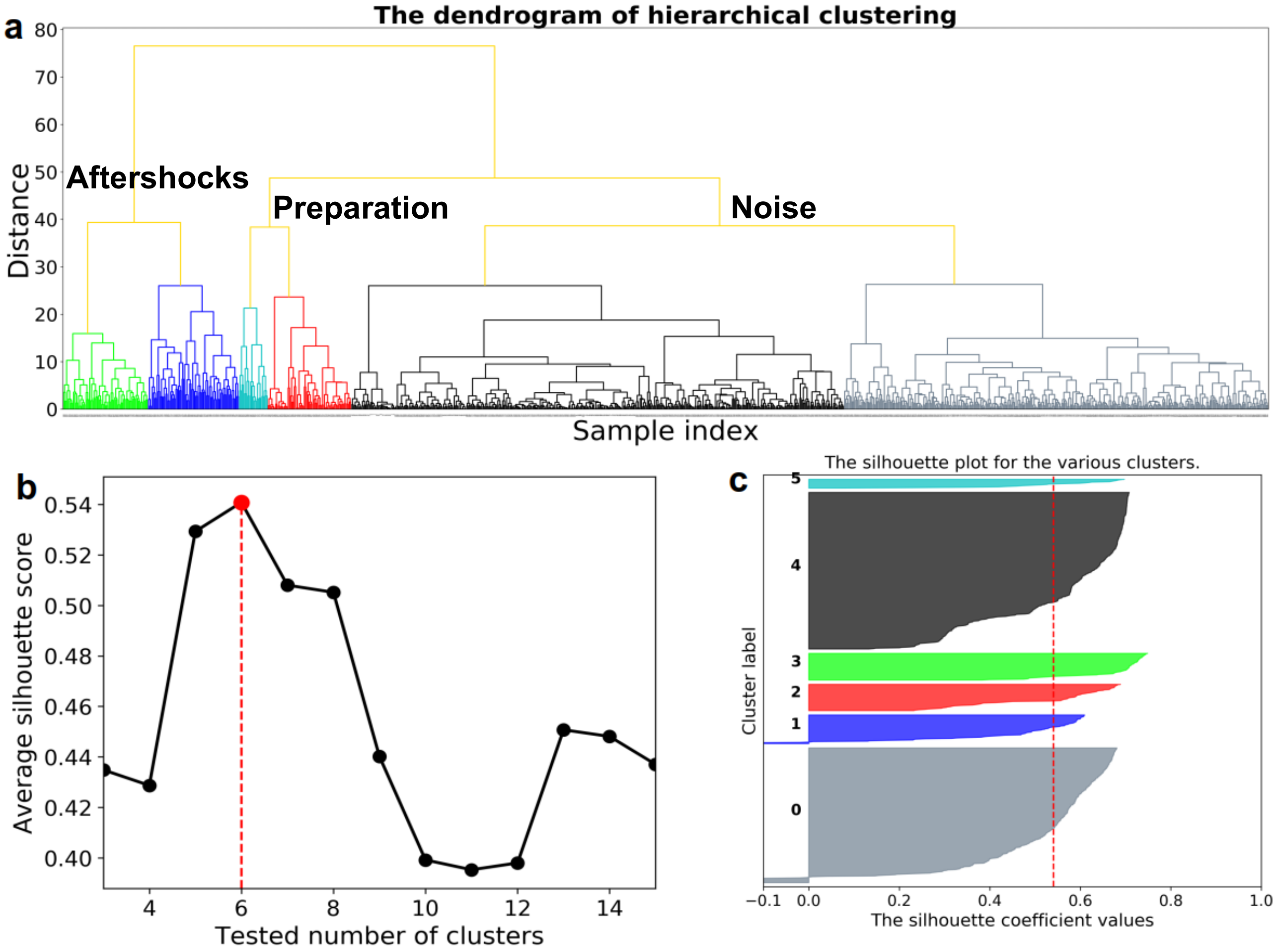


Cross-plot of different features (2-2.1 Hz)



Average cross-correlation coefficient between different features

Results: unsupervised analysis



Dimension of feature dataset:
285-D in the feature space;
966 time samples;

Different features are linearly normalized to 0-1 before clustering.

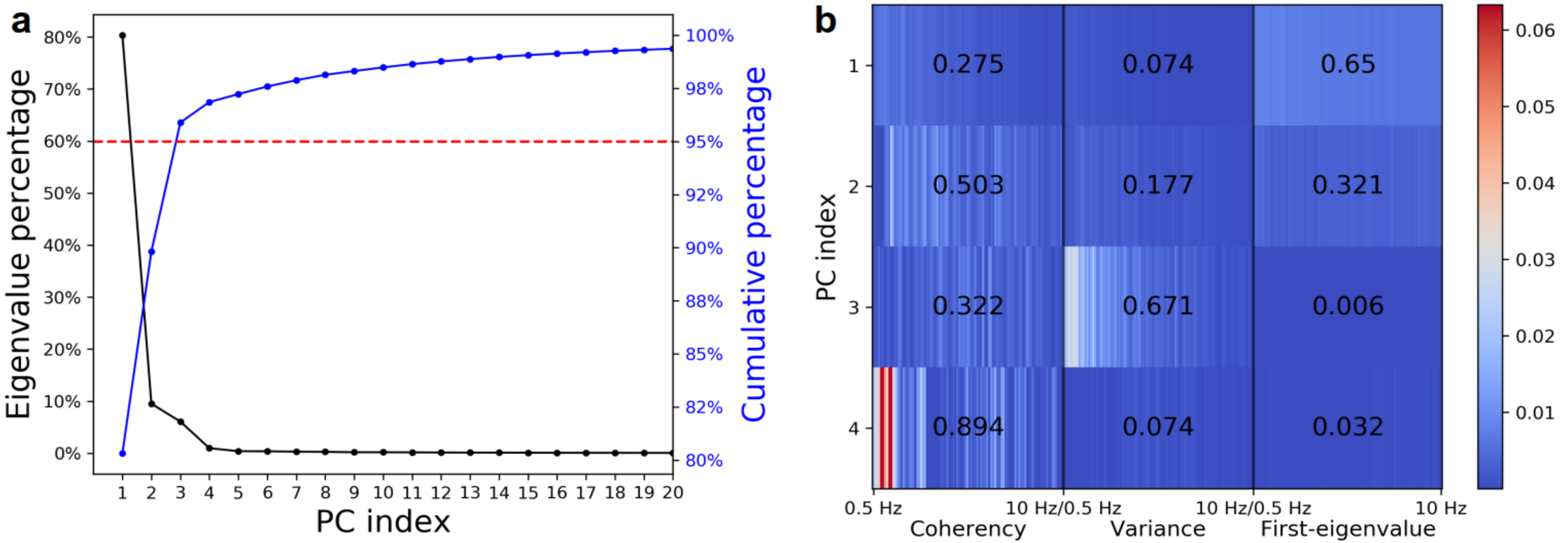
Hierarchical clustering:

- uneven cluster size;
- Non-flat geometry;
- Non-Euclidean distances

Determine the number of clusters using **Silhouette analysis**.

Number of clusters: 6

Results: unsupervised analysis



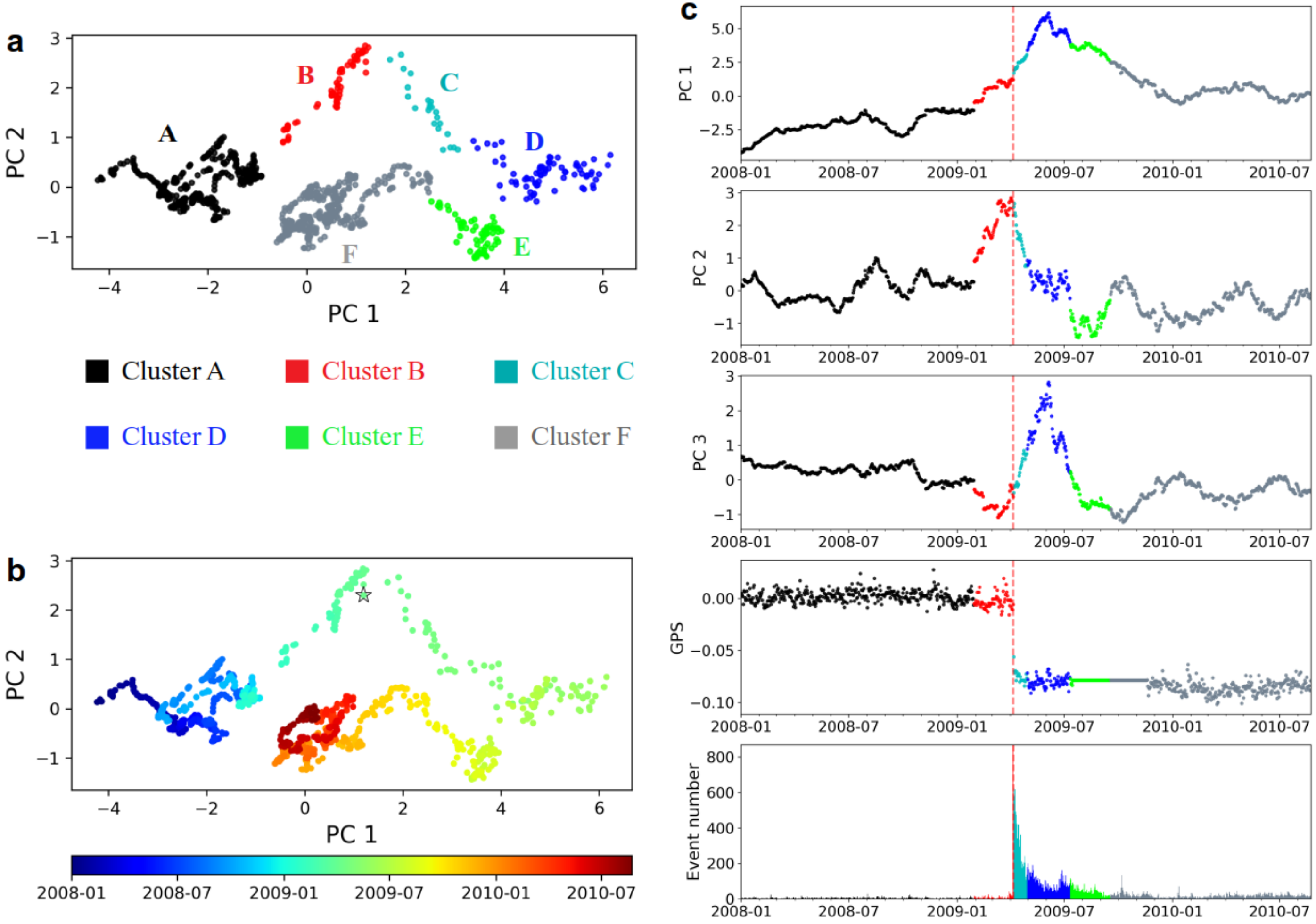
PCA of all the input features to (1) find suitable domain to **visualize** the clustering analysis; (2) identify the most **relevant** features and frequency ranges respect to different PCs.

PC1: Source energy **PC2: wavefield coherence and source localization**

PC3: Source variance: energy + coherence

Results: unsupervised analysis

PC1: Source energy **PC2: source localization**



- Clustering results in PC space clearly show there are patterns and systematic transitions in continuous wavefield.
- Temporal evolution of clusters highlights the transitional stages from a regime of fault activity to another one.

Cluster A: noise period

Cluster B: preparation phase

Cluster C: aftershock 1

Cluster D: aftershock 2

Cluster E: aftershock 3

Cluster F: recover to noise

Conclusions

- We have observed patterns and systematic transitions relating to the fault states from continuous seismic wavefield.
- The proposed array wavefield properties and unsupervised analysis enable us to identify the different regimes of fault activity, which can be important for hazard monitoring and fault physics studies.
- The proposed analysis method can be implemented as a powerful and complementary tool (in addition to the seismic catalog) to directly assess the fault state and track its temporal evolution in a blind way.