

Preliminary results for Space-Time Clustering of Seismicity and its Connection to Stimulation Processes, in North-Western Geysers Geothermal Field

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Trieste



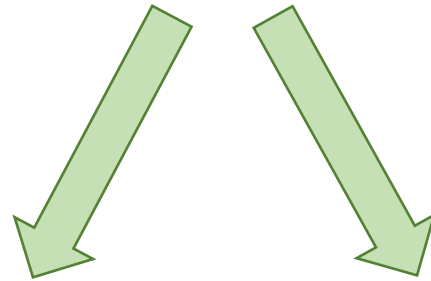
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Aim of the Study

Utilize the high quality relocated data from NW Geysers



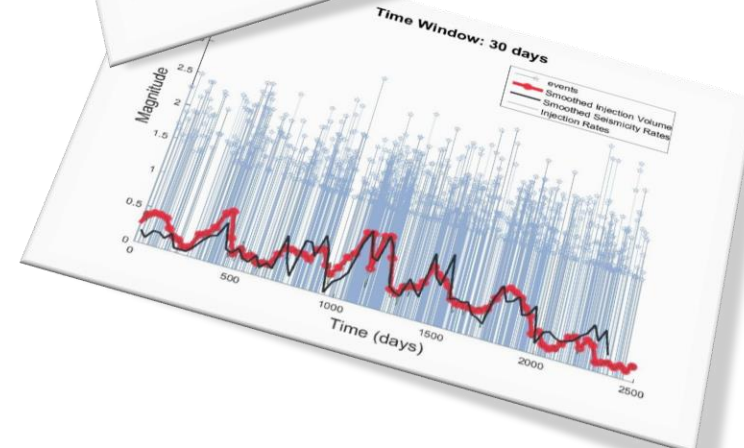
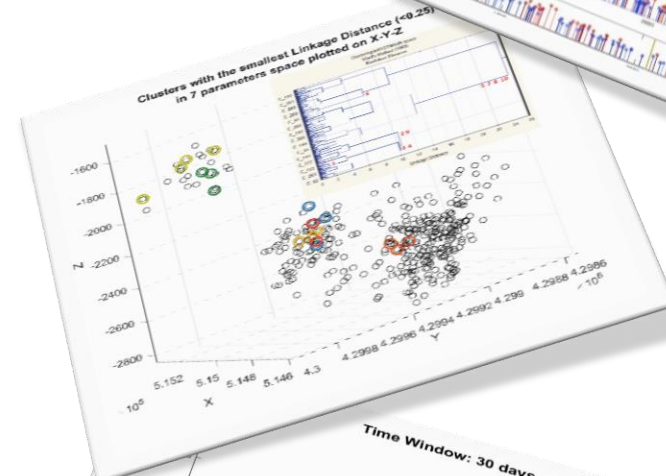
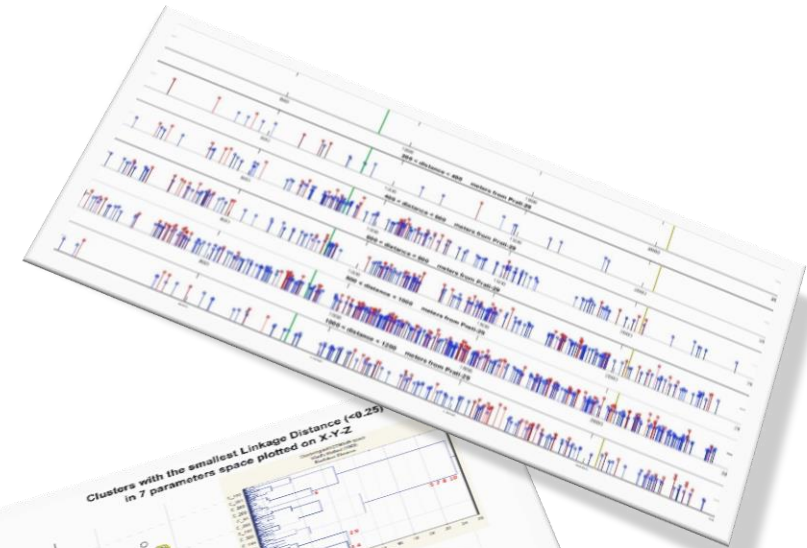
**Cluster Analysis in
Multidimensional
Parameter Space**

**Spatio-temporal
Correlation
between Seismicity
and Injection**



Outline

- Data
- Methodology
 - Cluster Analysis
 - Correlation Analysis
- Results (*Preliminary*)
- Conclusions (*Preliminary*)
- References



Data

1275 events in Relocated Catalog of NW Geysers (*Martinez-Garzon et al., 2014; Kwiatek et al., 2015*)

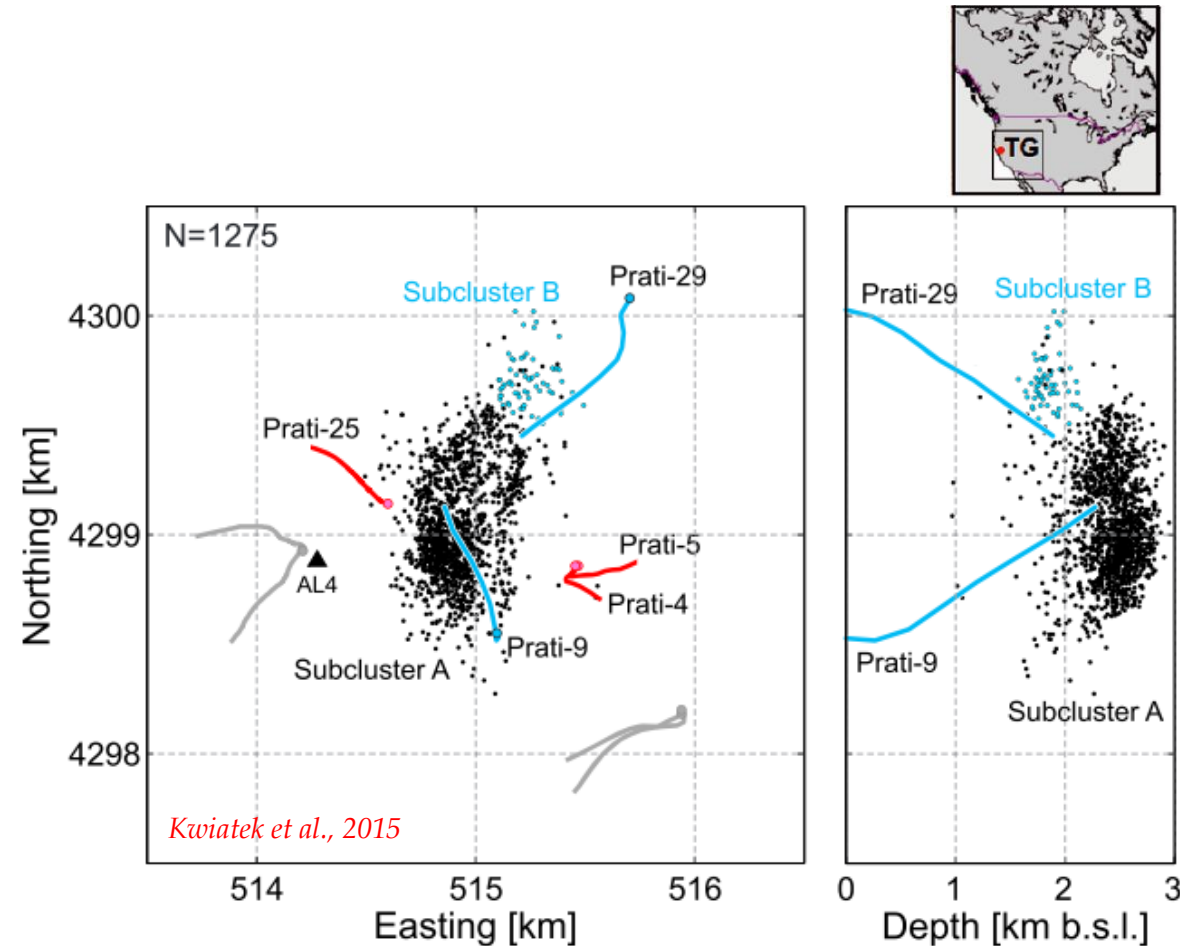
- For Correlation Analysis:
1121 events (Connected with Prati-9)

$$M_C=1.4$$

Daily Injection Volumes/Rates

- For Cluster Analysis
353 events

Spectral Parameters Calculated



Methodology – Cluster Analysis

- Every seismic event can be represented as a point in a multi-parameter phase space, described by a set of parameters $[X_1, \dots, X_n]$ (e.g. $[t, x, y, h, M_0, E_s, \Delta\sigma]$) with CDFs as F_{X_1}, \dots, F_{X_n} , respectively.

Clustering:
Based on Distances
Among these Points



Challenge:
Dealing with
Different Metrics of
Parameters

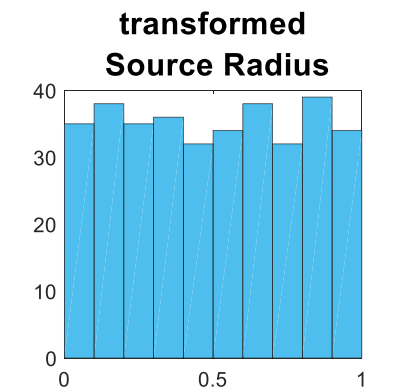
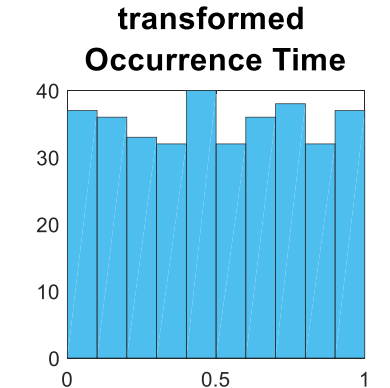
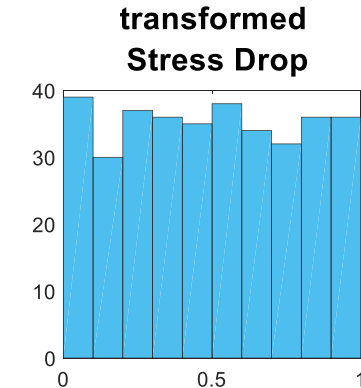
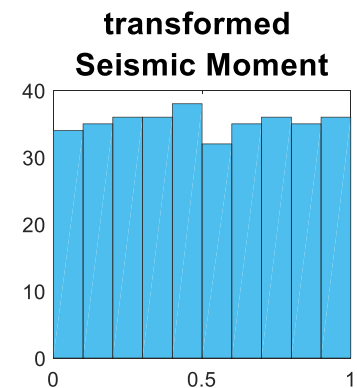
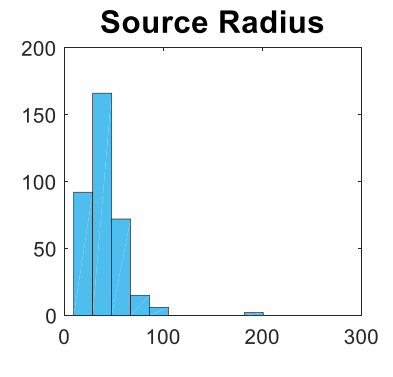
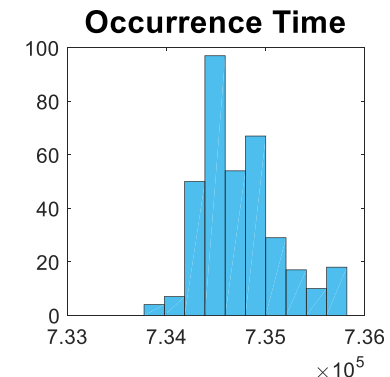
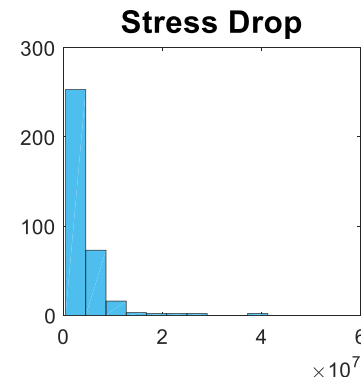
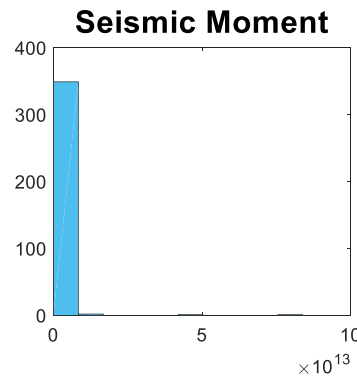
Methodology: Transformation to Equivalent Dimensions (Lasocki, 2014)

- Transformation of X_i into $U_i = F_{X_i}(X_i)$ $i=1, \dots, p$. U_i is uniformly distributed in $[0,1]$.

- Each event is now parameterized by the vector $U(U_1, \dots, U_p)$ in the Euclidean metric p -dimensional hyperspace.

- The distance between 2 events k and l is defined as:

$$d(k, l) = \sqrt{\sum_{i=1}^n [U_i(k) - U_i(l)]^2}$$



Methodology: Cluster Analysis

- Clustering of seismic events in multidimensional parameter space by applying the Ward (1963) method - hierarchical families of mutually exclusive datasets are identified

Are closely located events also similar in terms of source properties?



Methodology: Correlation Analysis

Evaluation of correlation between spatio-temporal seismicity distribution and variation of the injection parameters:

- **Evaluating significance of seismicity rate changes between subsequent time windows**
 - *Binomial test*
- **Time series correlation metrics/ smoothing data**
 - *Cross correlation of time series*
 - *2 sample Kolmogorov-Smirnov test*
- **b-values evaluation and their relation with seismicity rates/ fluid injection**



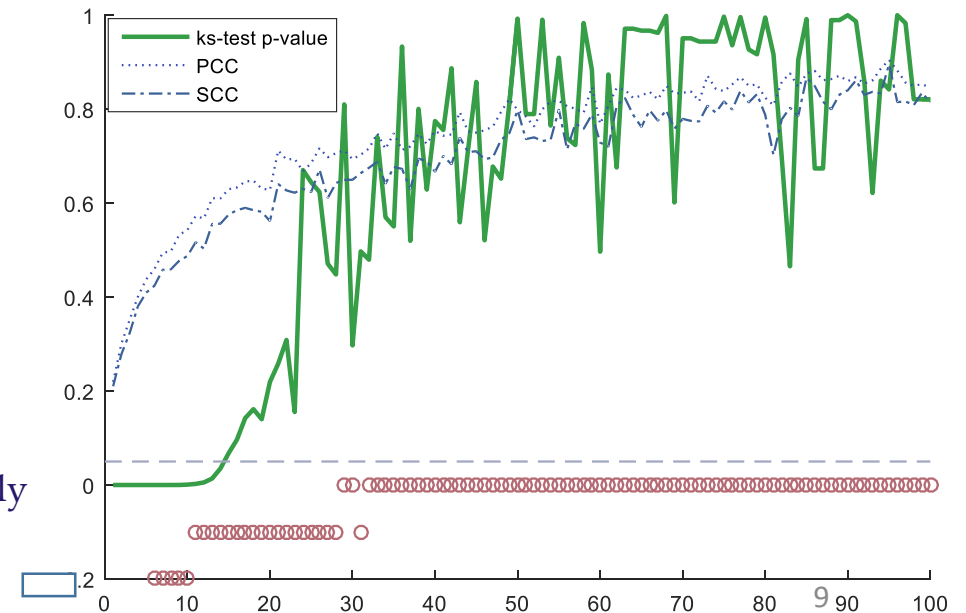
Methodology: Correlation Analysis

Those metrics are applied to evaluate correlation for:

- Different distances from injection well Prati-9
- Different minimum magnitude thresholds
- Original and smoothed time-series

- Time series correlation metrics applied for determining the optimal time window width (W_p) for smoothing

- $P_{W_p}^{KS_Test} > 0.05$
- $CC_{W_p}^{\max}$ is systematically achieved for lag=0

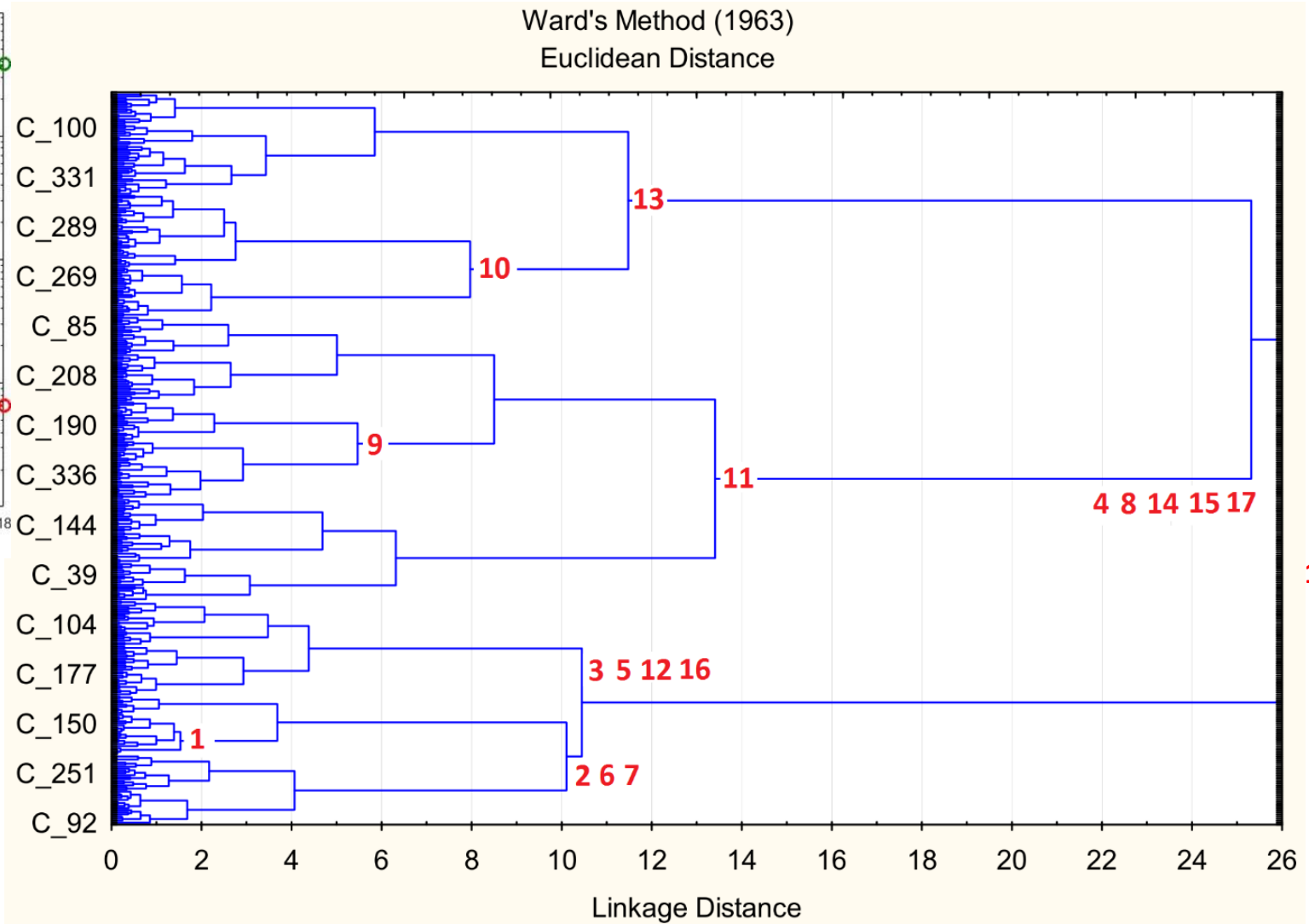
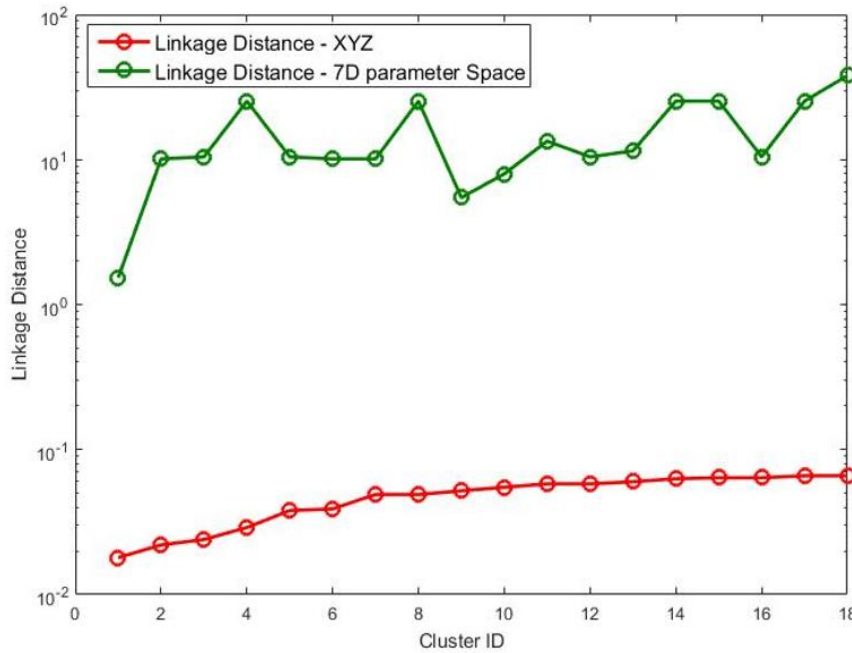


Cluster Analysis Results



18 clusters with $LD < 0.07$ in transformed XYZ were found

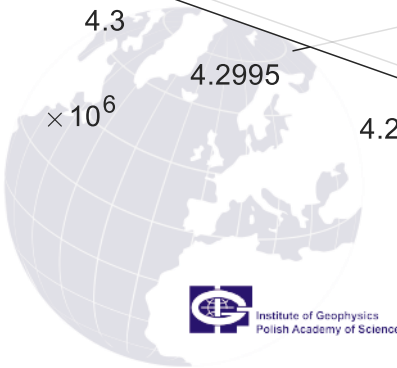
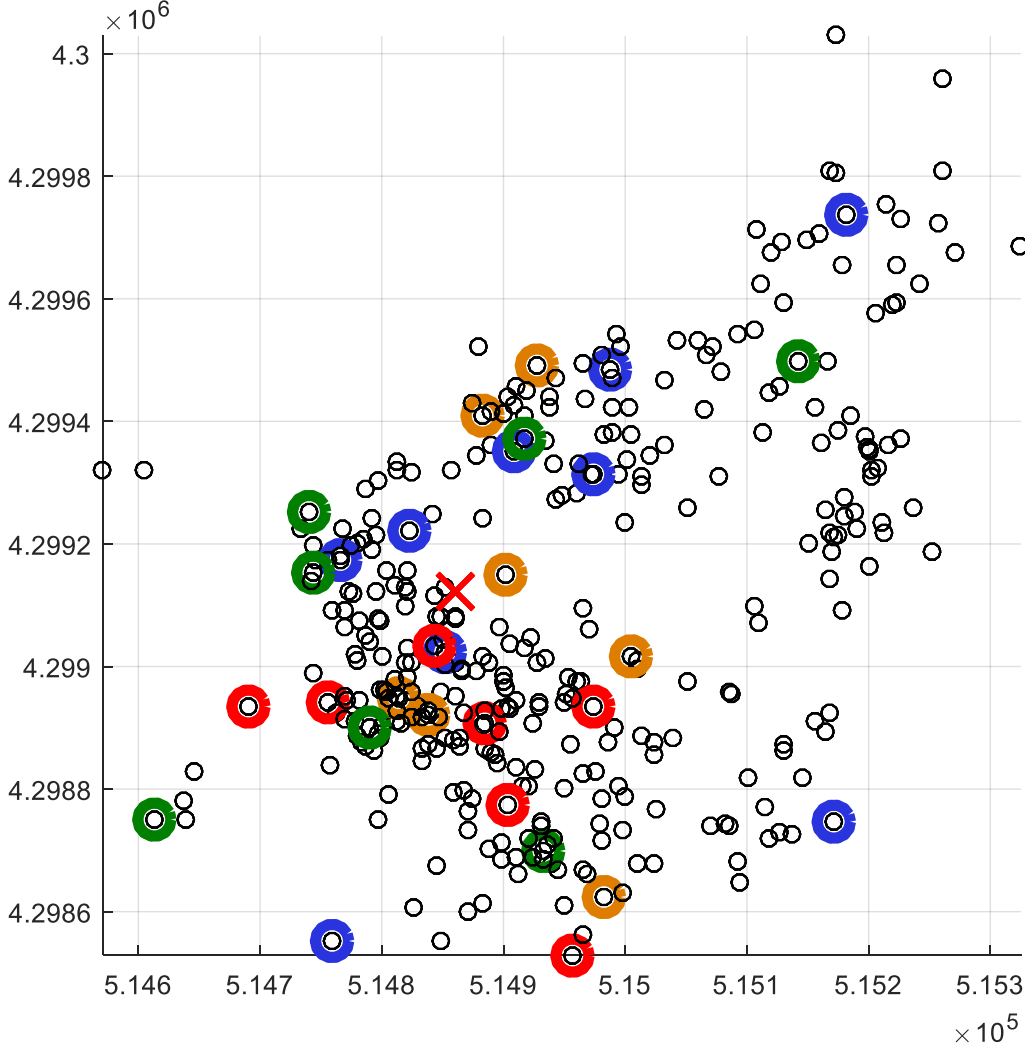
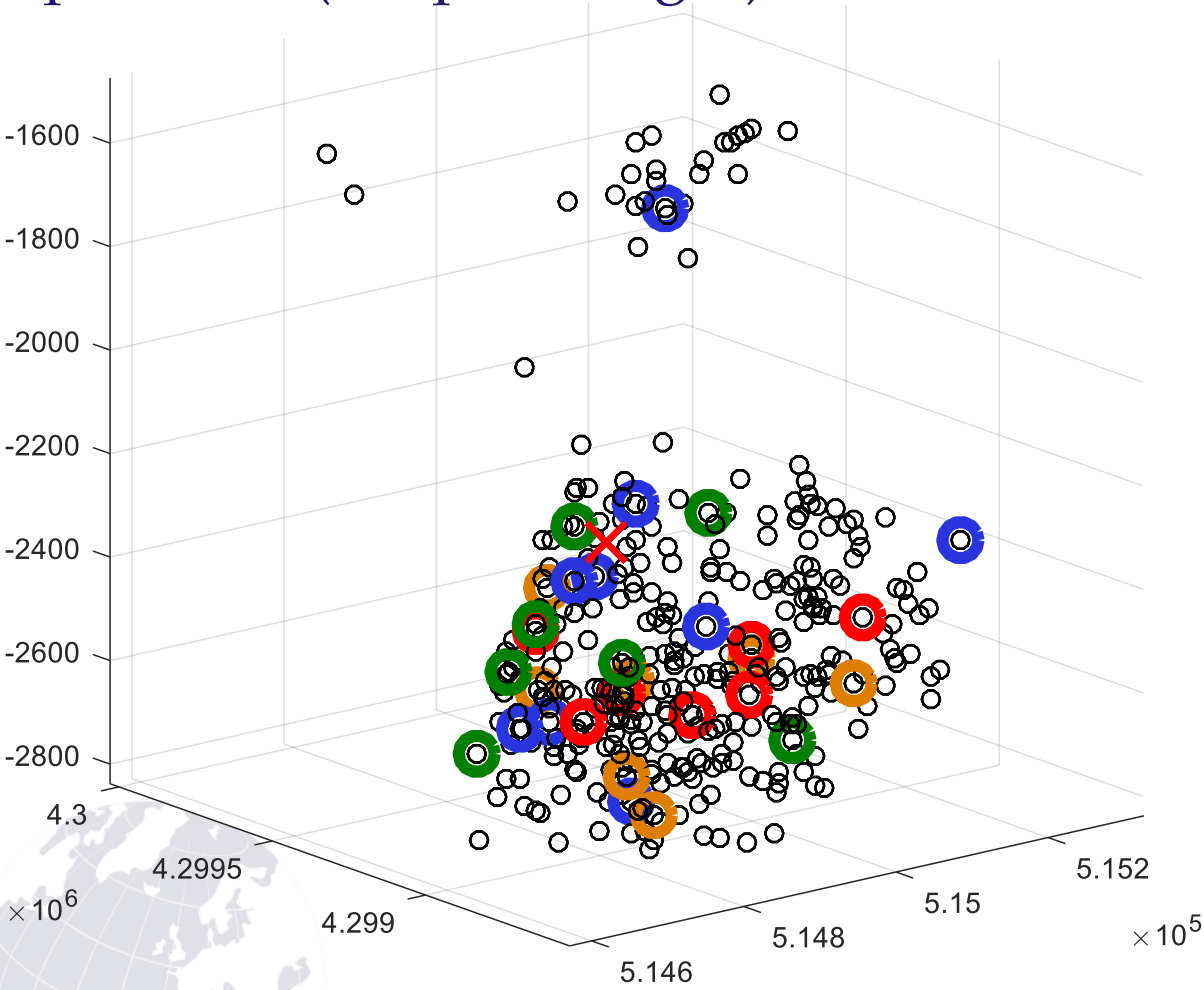
LD of those clusters, in 7-parameter space (Space-Time-Spectral)



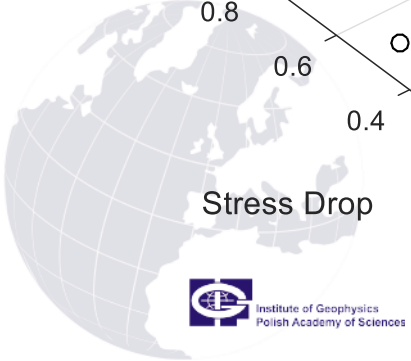
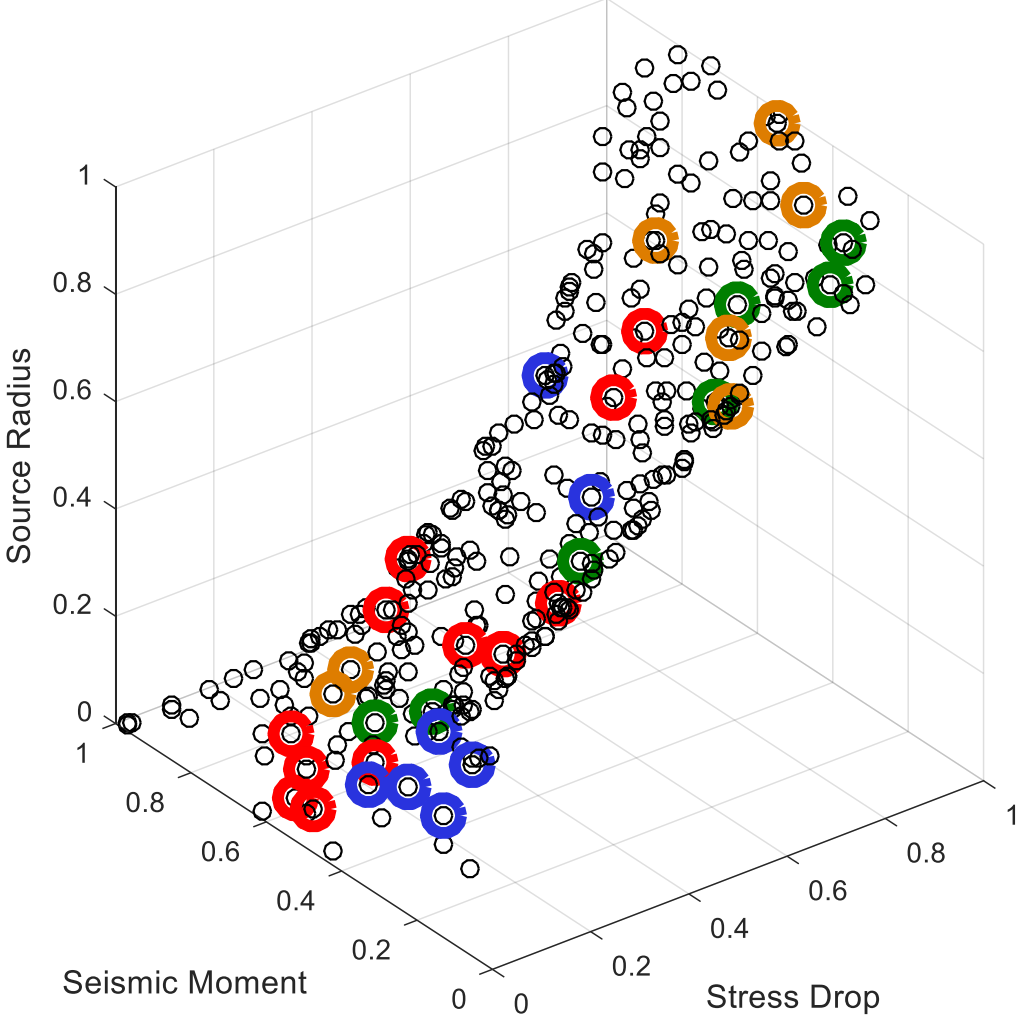
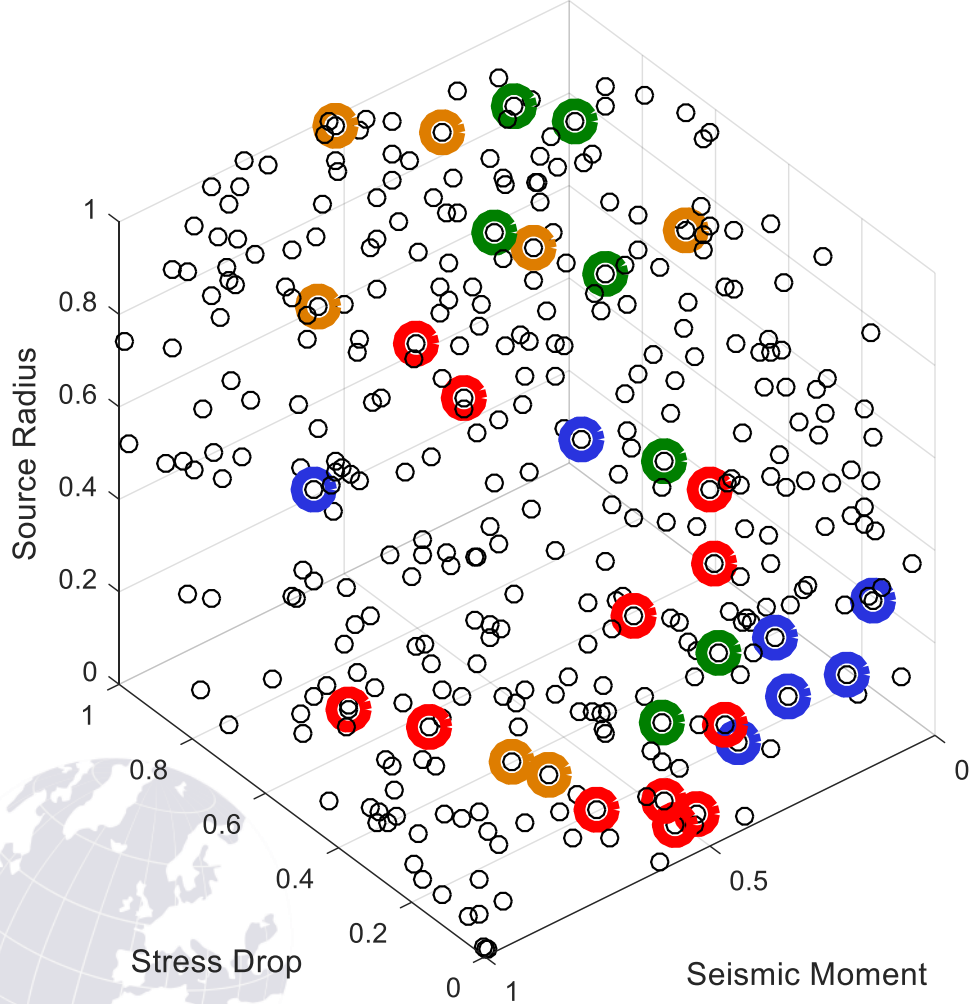
18 - LD~38



4 families of the most linked clusters (LD<1.5, N>6) in Spectral Parameter Space (Sd, R, M₀ - colored circles) plotted in 3D spatial coordinates (XYZ plot - left) and 2D epicentral (XY plot - right).



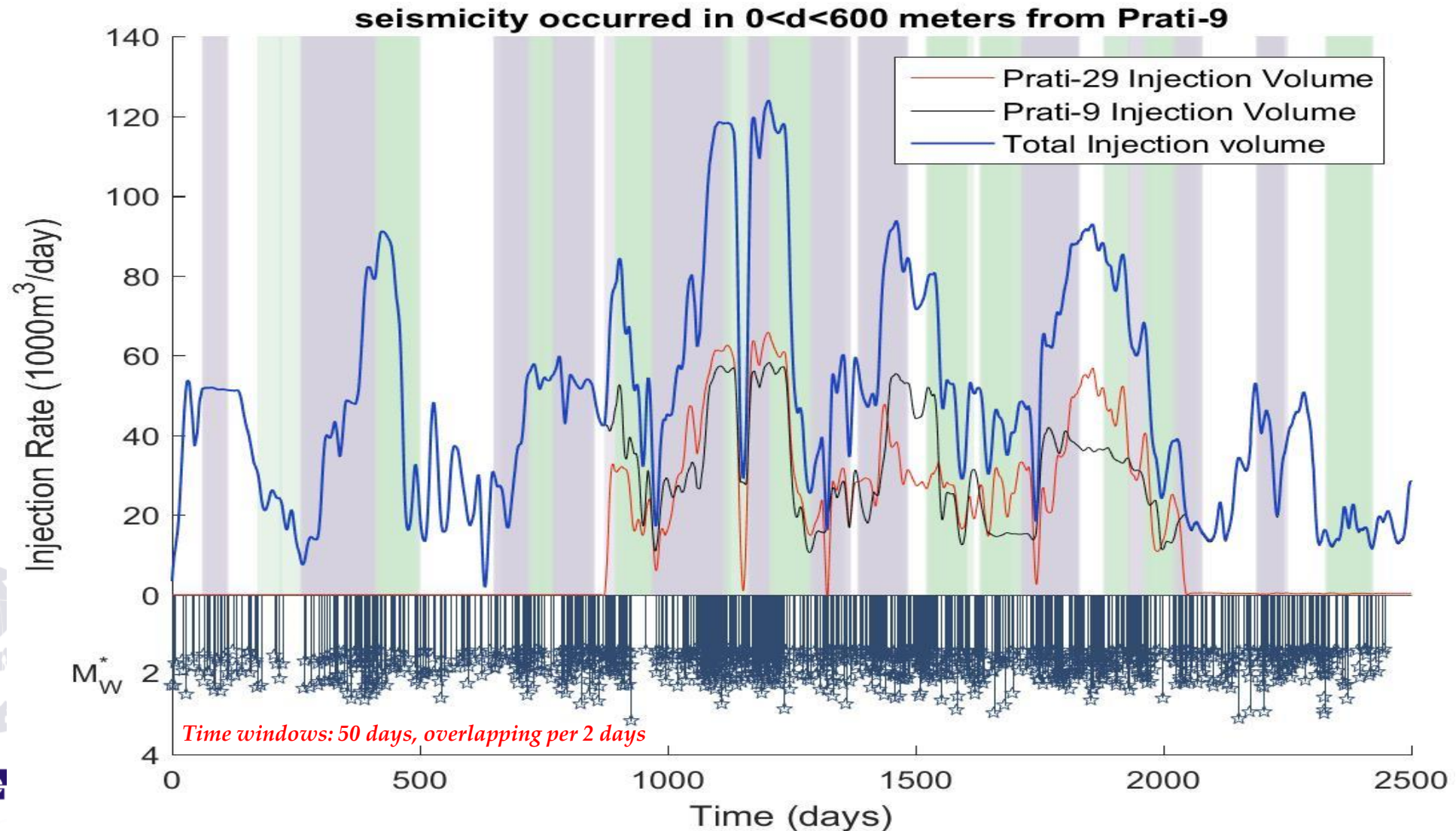
4 families the most linked clusters (LD<0.2, N>6) in XYZ coordinates (colored circles) plotted in 3D Spectral Parameter Space (Sd, R, M₀)



Correlation Analysis Results



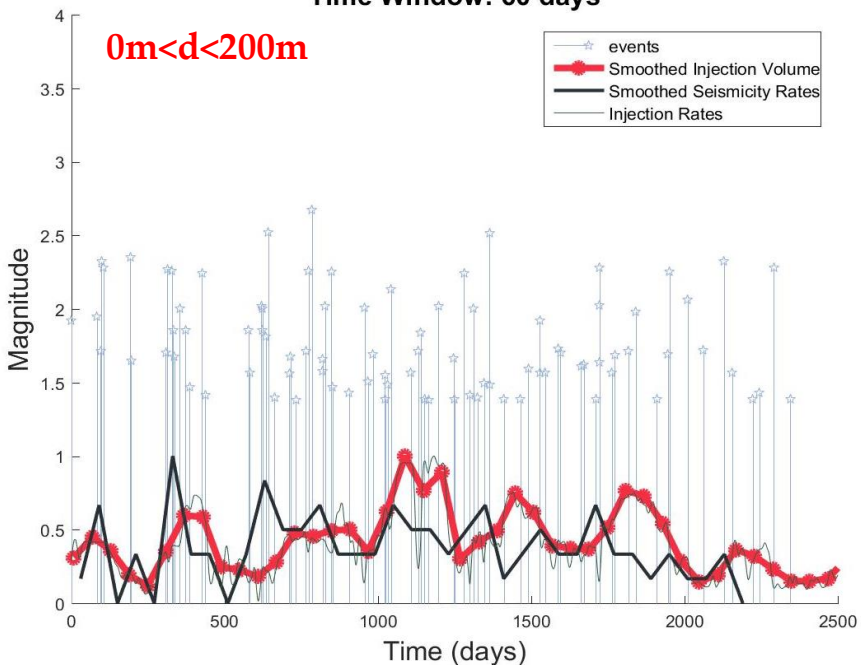
Correlation Analysis



Correlation Analysis

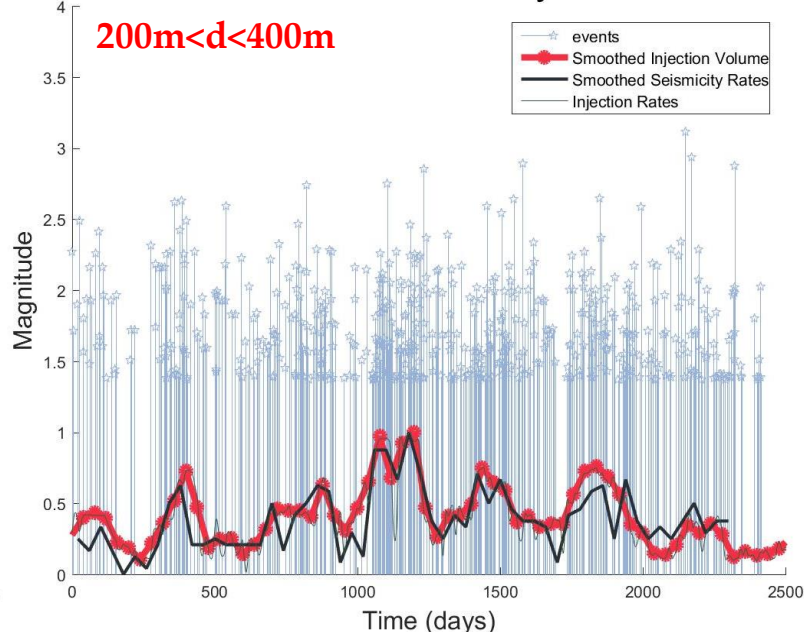
Time Window: 60 days

$0m < d < 200m$



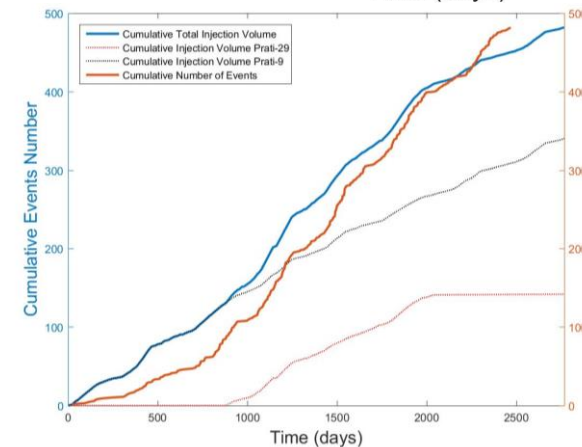
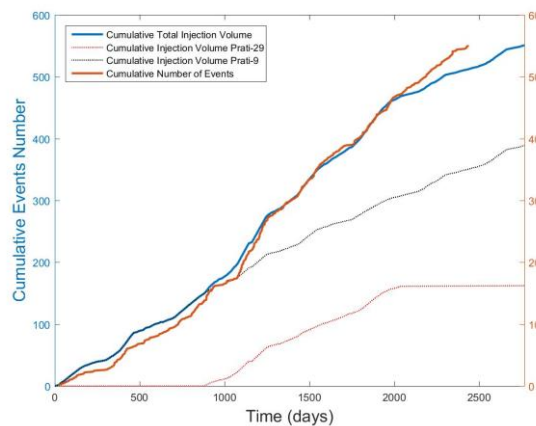
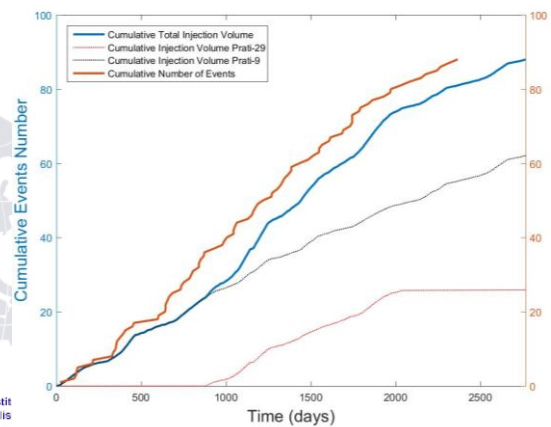
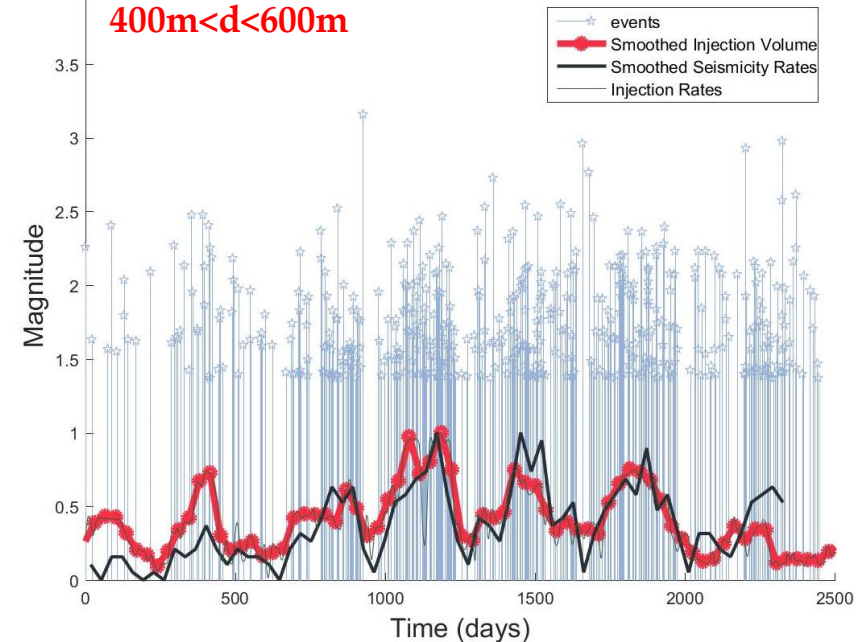
Time Window: 40 days

$200m < d < 400m$



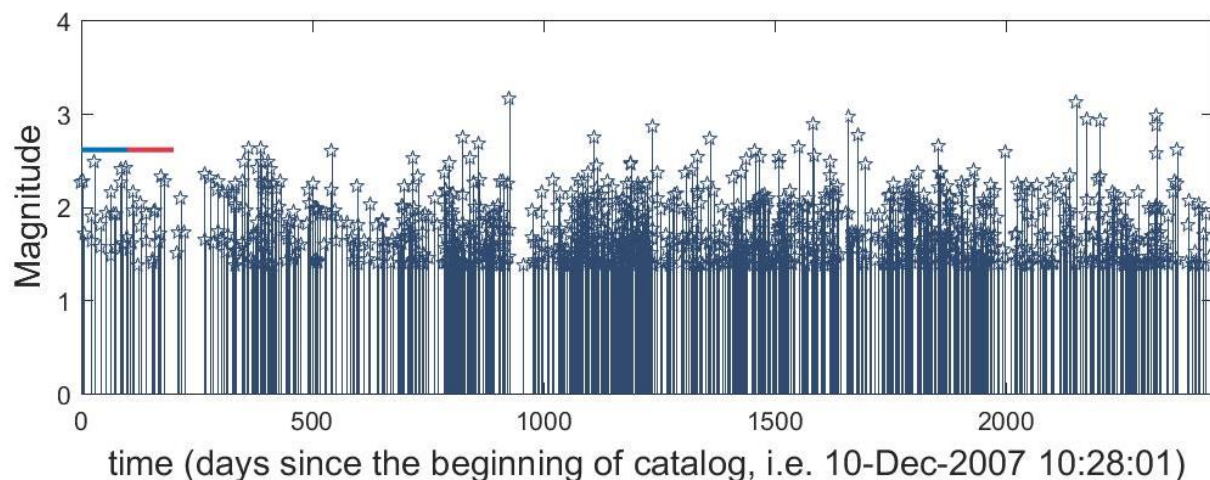
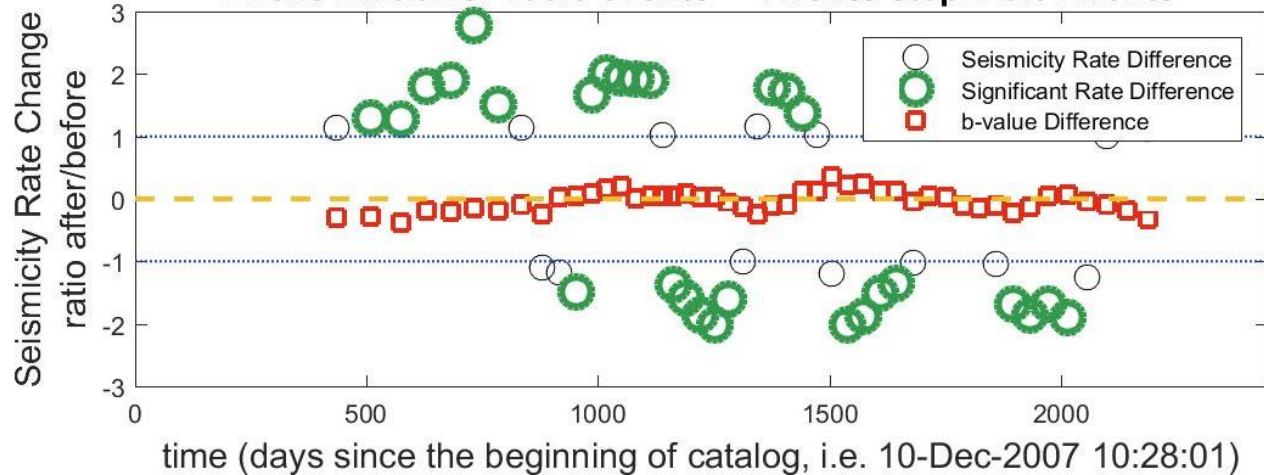
Time Window: 35 days

$400m < d < 600m$

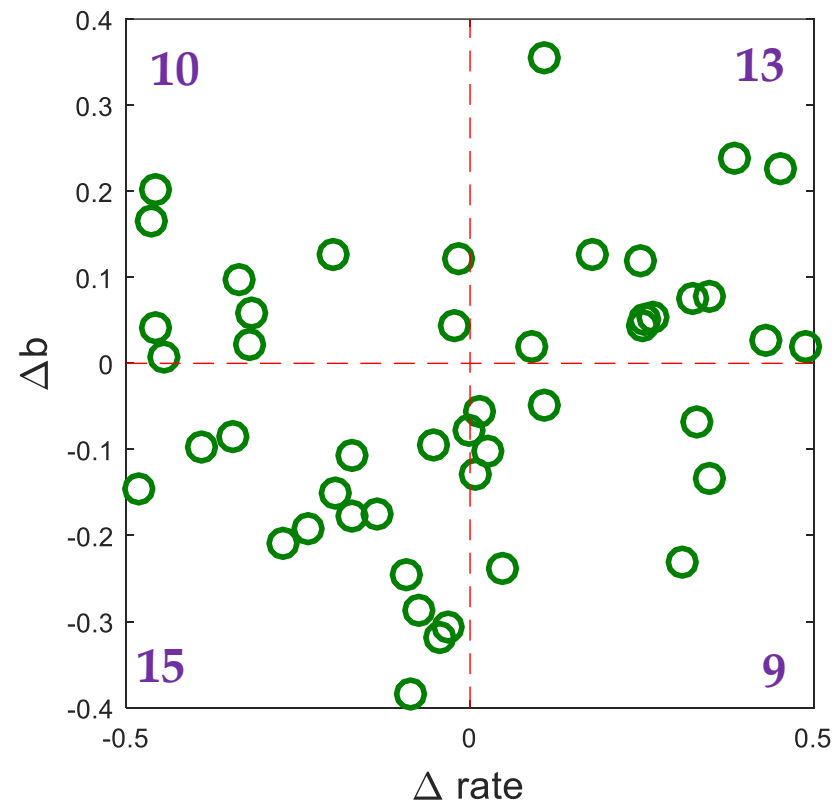


b-value Analysis

Event windows: 100.0 events - Events step: 20.0 Events



59.6% positive correlation



Conclusions (Preliminary)

- Similar locations of events do not necessarily imply a similarity of the source characteristics of these events and vice versa
- Correlation between seismicity/injection is significant for distances $> 200\text{m}$ from Prati-9
- No clear influence of injection on b-values was detected



Acknowledgements

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<http://www.sheerproject.eu/>



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