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

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SHale gas Exploration and Exploitation induced Risks

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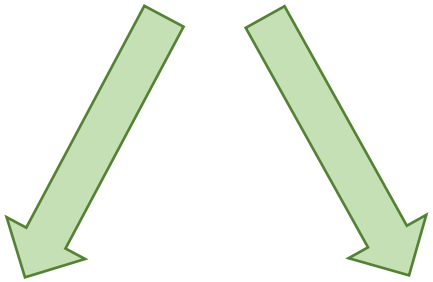
Aim of the Study

Utilize the high quality relocated data from NW Geysers

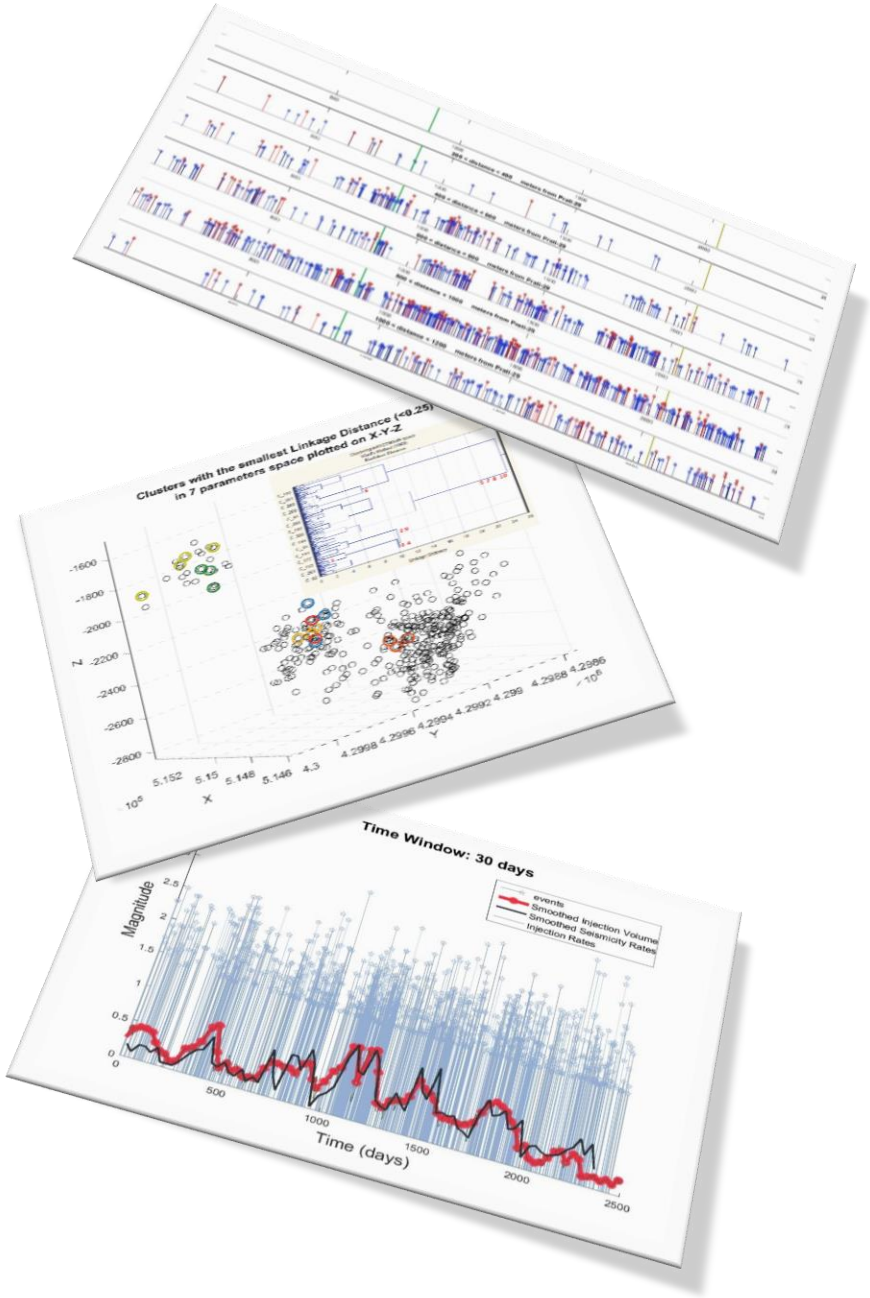


Cluster Analysis in Multidimensional Parameter Space

Spatio-temporal Correlation between Seismicity and Injection

Outline

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

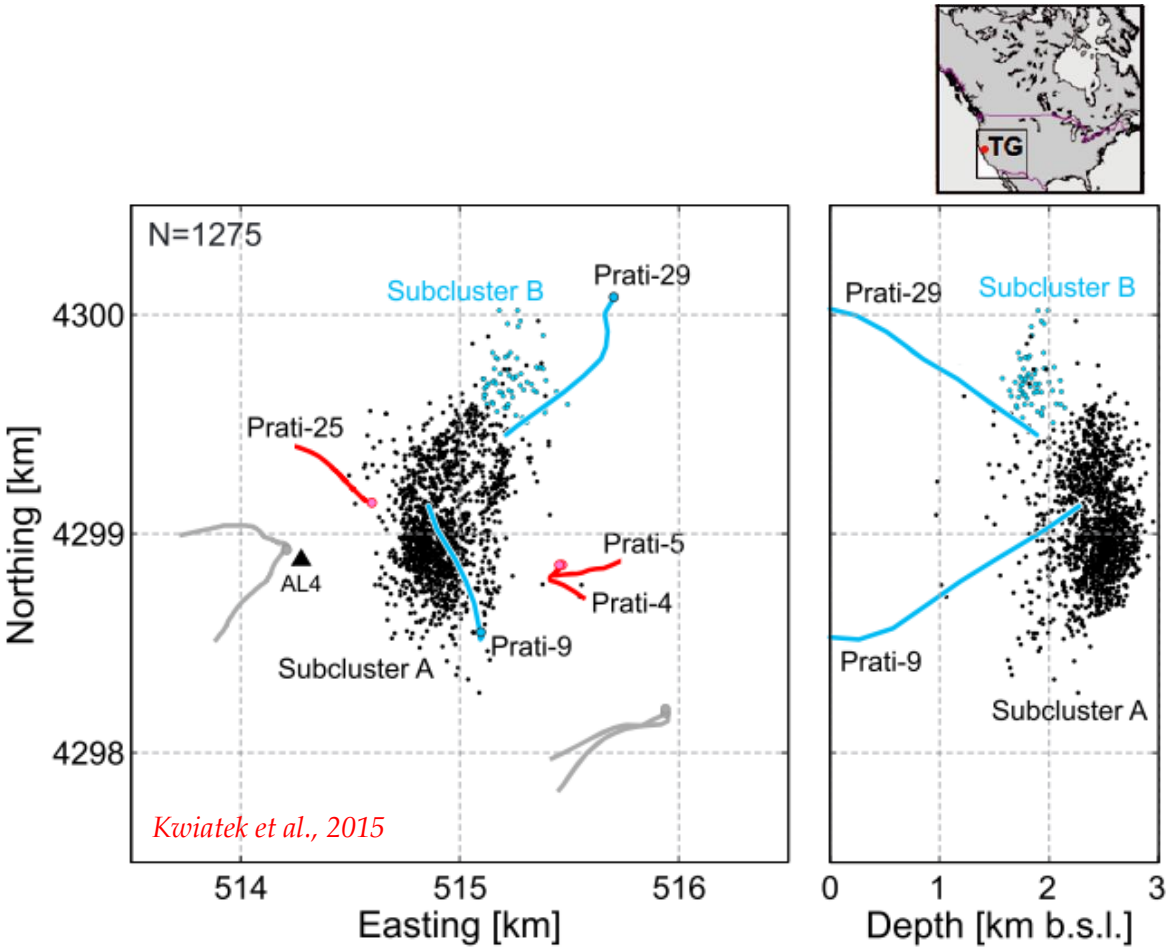


Data

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

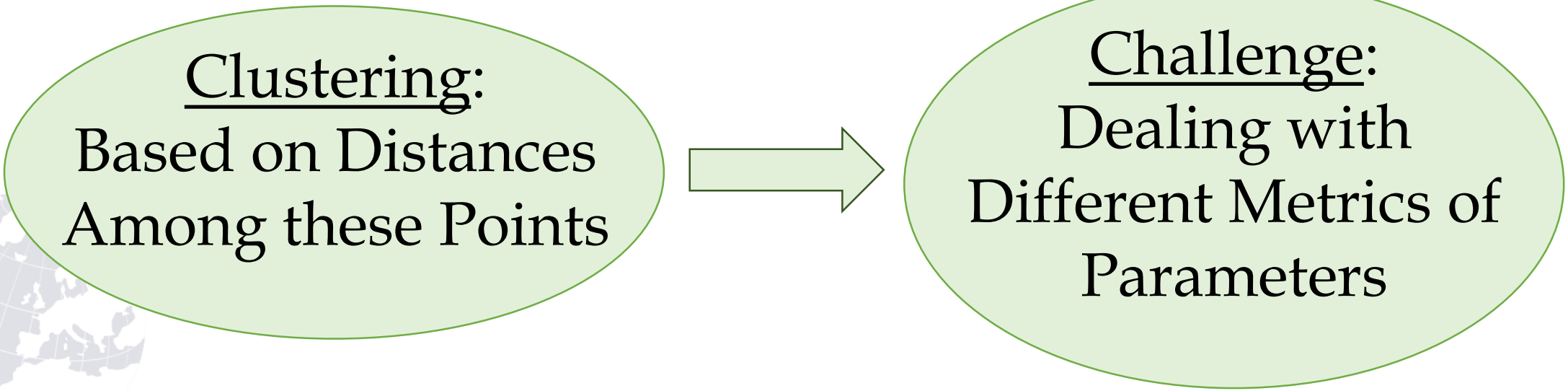
- For Correlation Analysis:
  1121 events (Connected with Prati-9)
  M_C=1.4
  Daily Injection Volumes/Rates

- 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, …, X_n] (e.g. [t, x, y, h, M_0, E_s, $\Delta\sigma$]) with CDFs as F_{X1},…F_{Xn} , respectively.



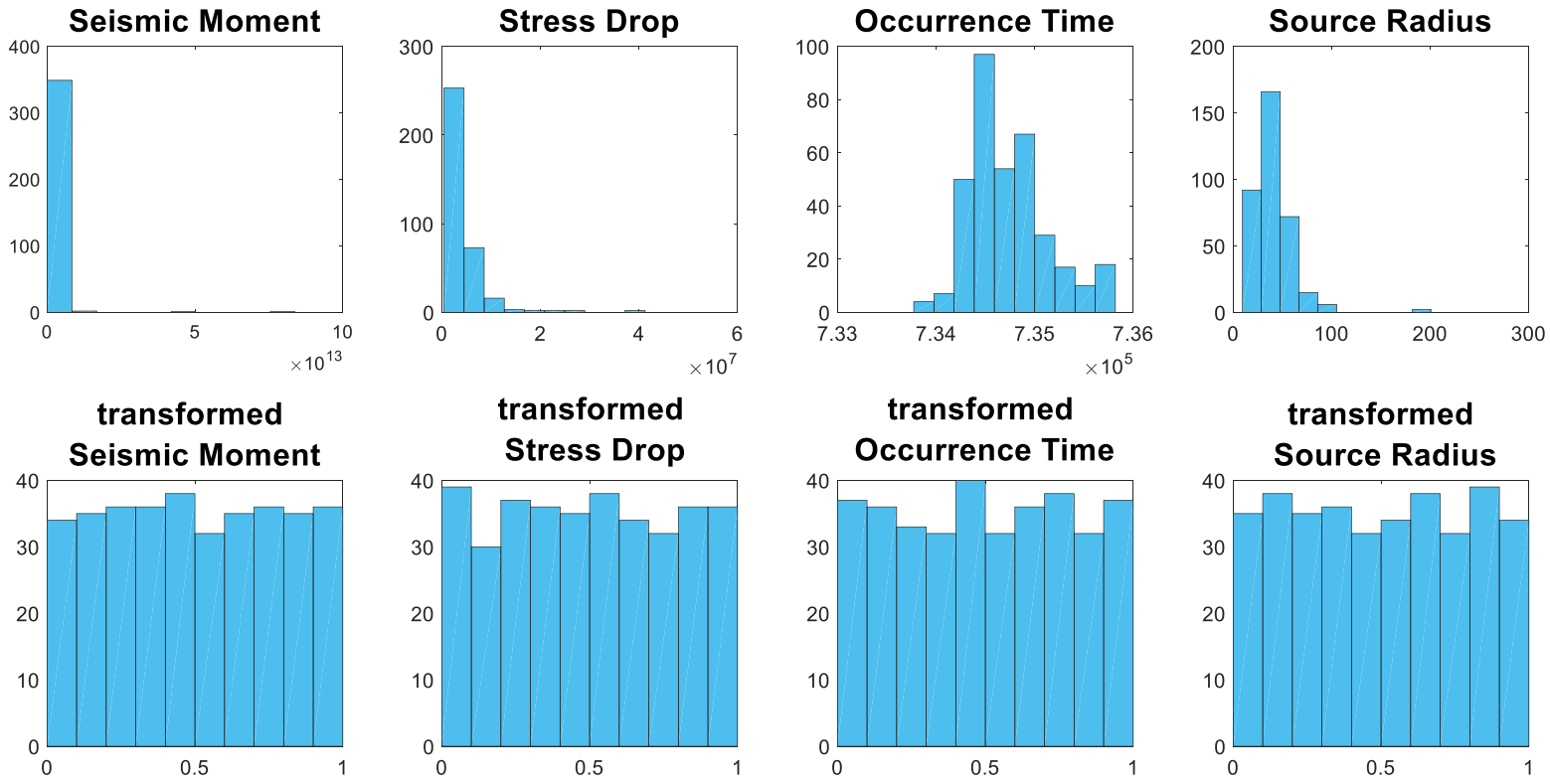
Methodology: Transformation to Equivalent Dimensions *(Lasocki, 2014)*

- Transformation of X_i into $U_i=Fx_i(X_i)$ i=1,…,p. U_i is uniformly distributed in [0,1].

- Each event is now parameterized by the vector $U(U_1,\ldots,U_p)$ 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

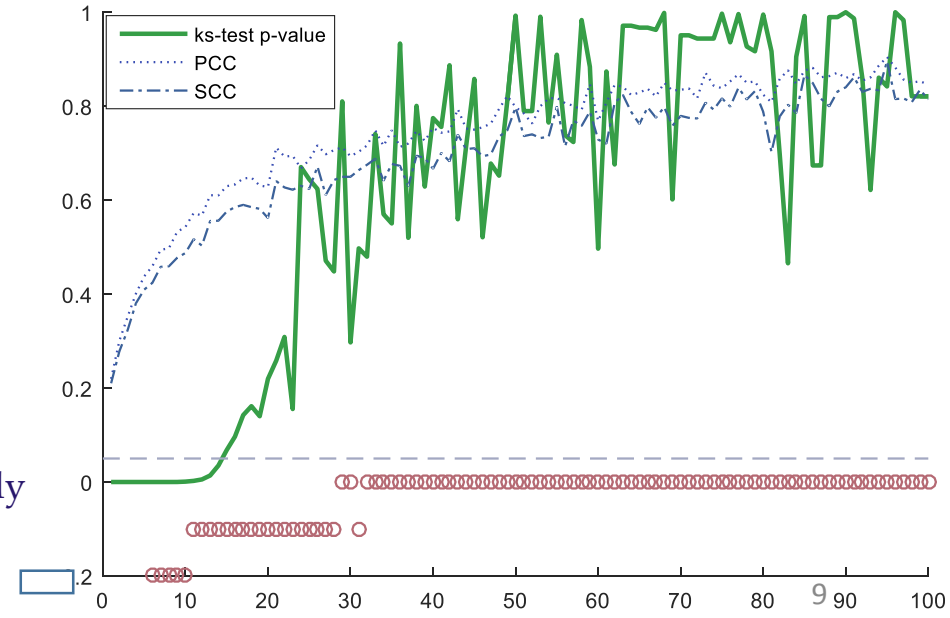
Those metrics are applied to evaluate correlation for:

- 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

i) $P_{Wp}^{KS\_Test} > 0.05$

ii) CC_{Wp}^{max} is systematically achieved for lag=0



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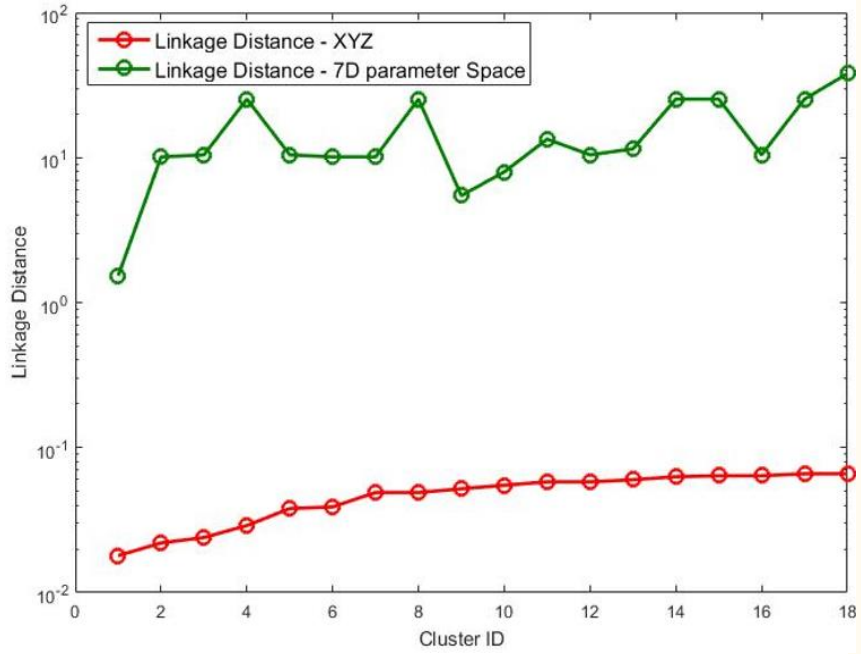
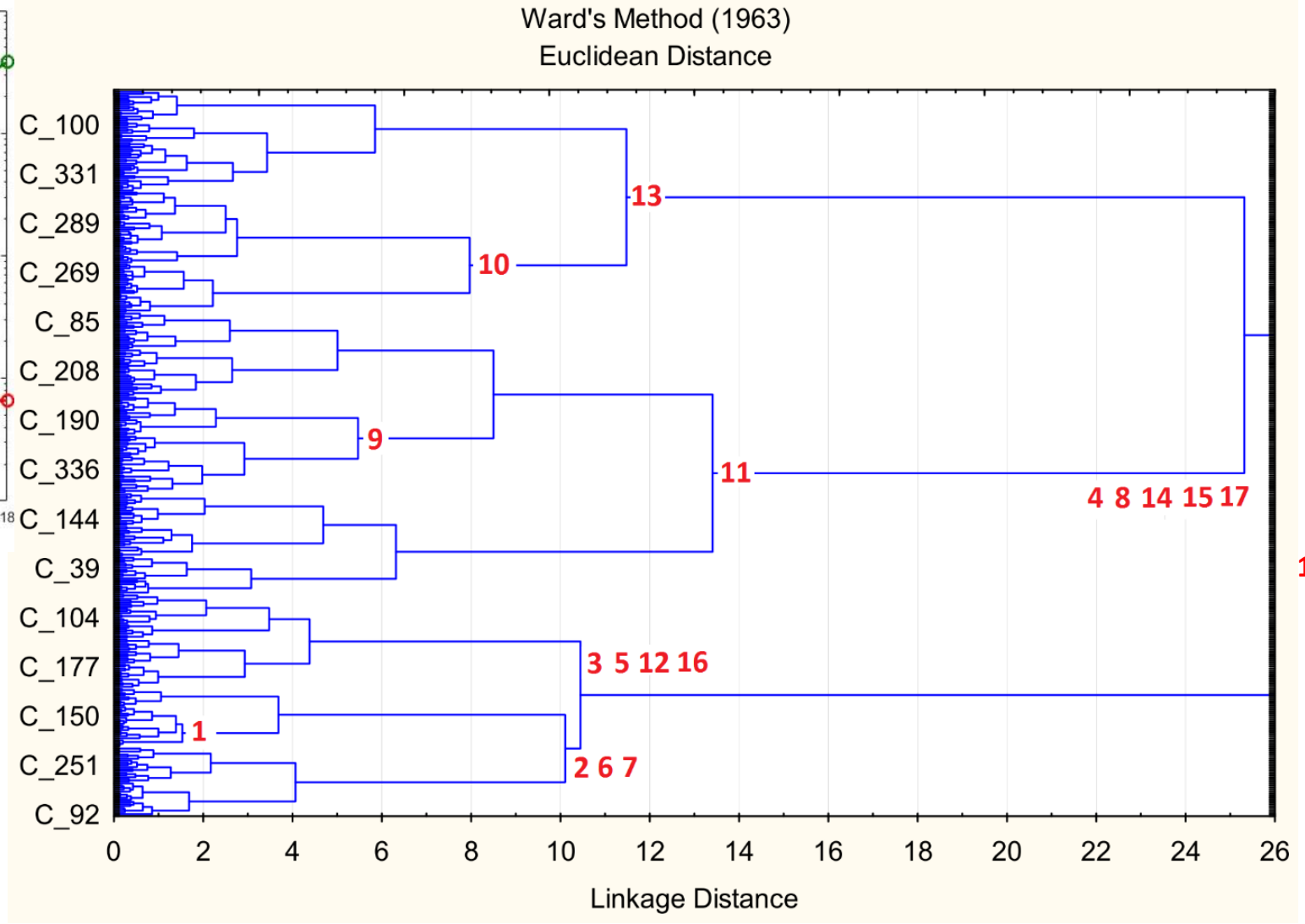
Cluster Analysis Results

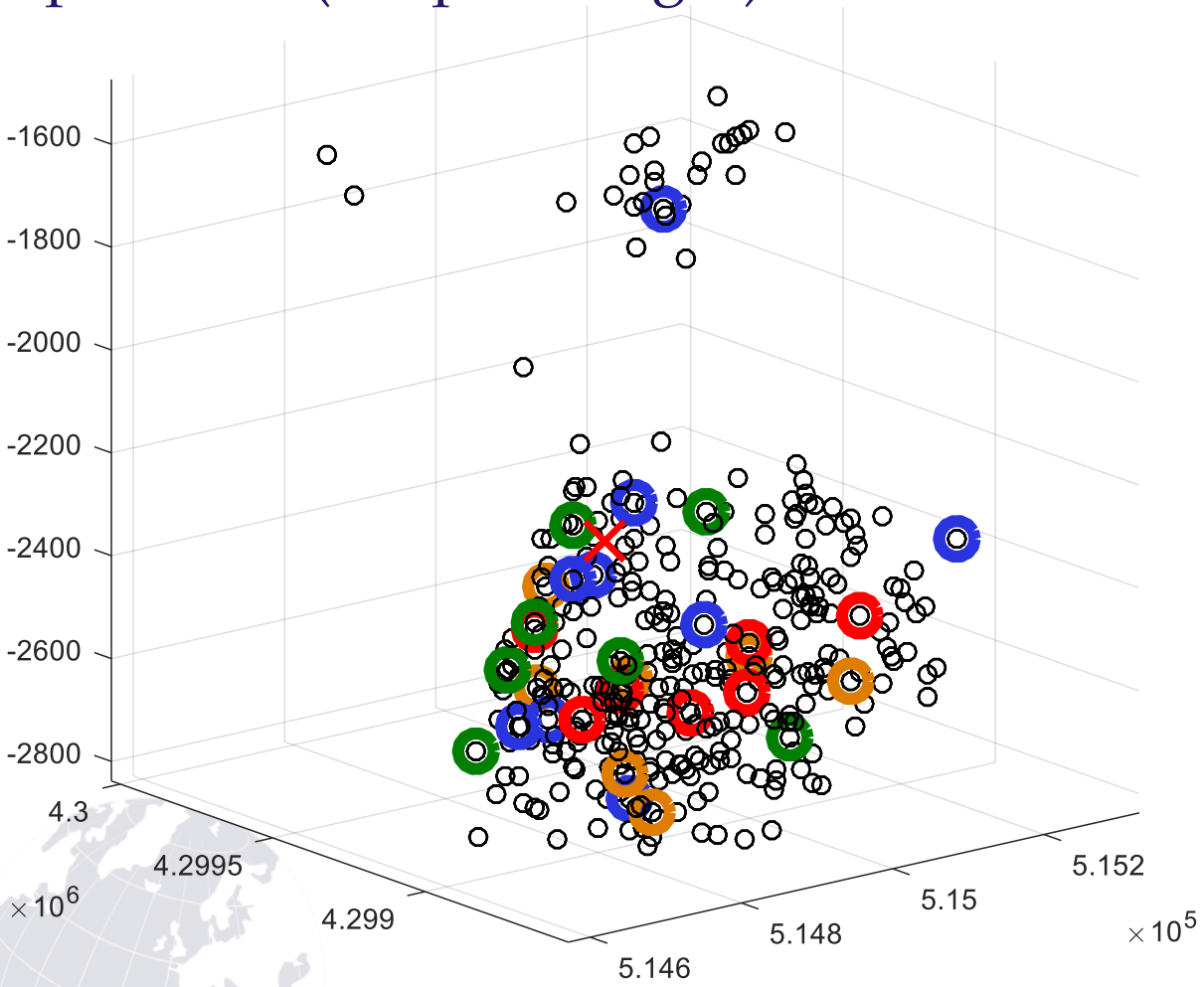
18 clusters with LD<0.07 in transformed XYZ were found
LD of those clusters, in 7-parameter space (Space-Time-Spectral)

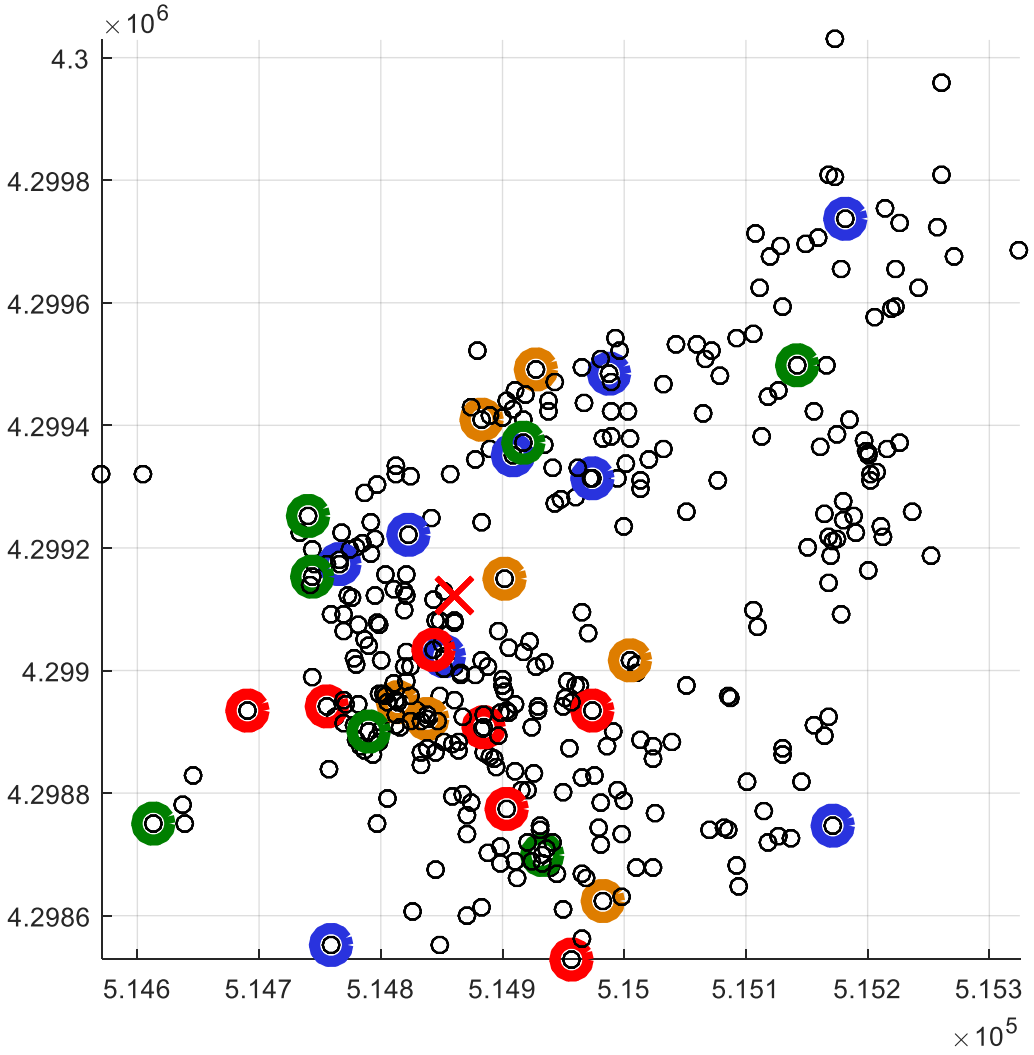




18 – LD~38

4 families of the most linked clusters (LD<1.5, N>6) in Spectral Parameter Space (Sd, R, M_0 - colored circles) plotted in 3D spatial coordinates (XYZ plot – left) and 2D epicentral (XY plot – right).





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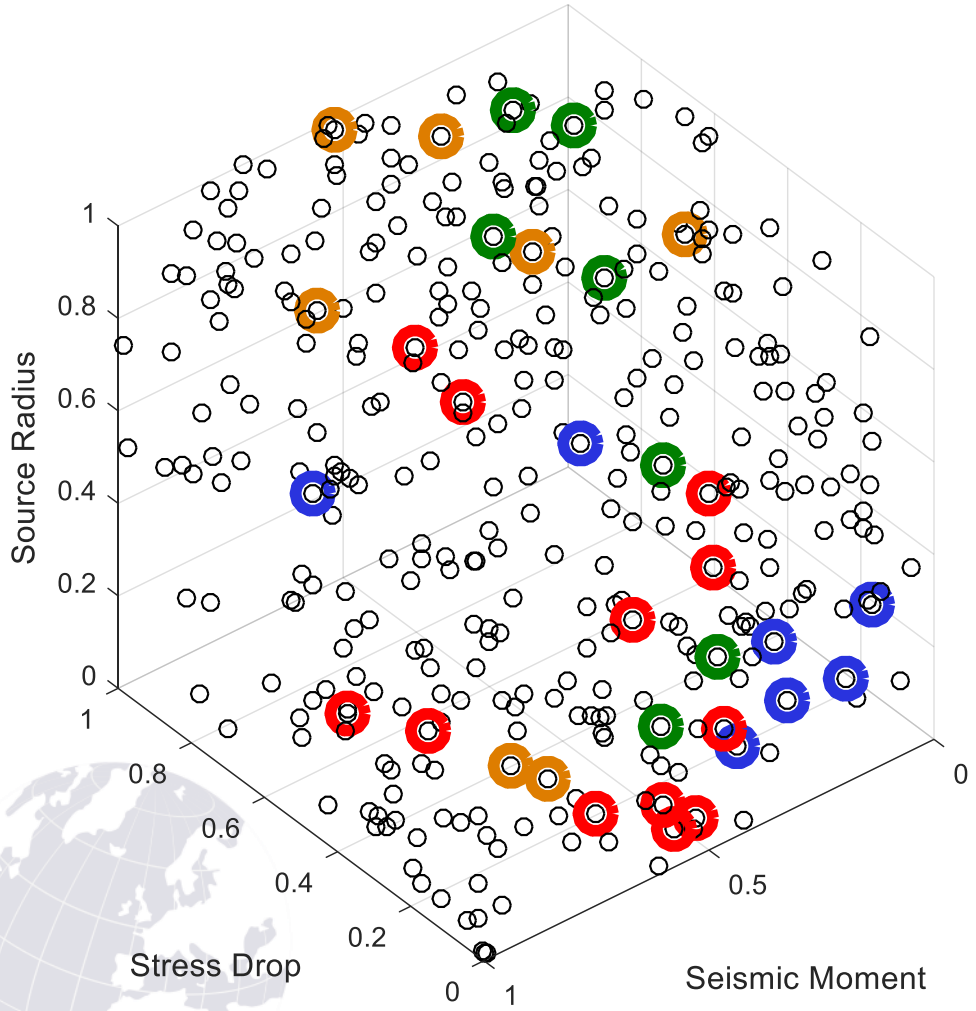
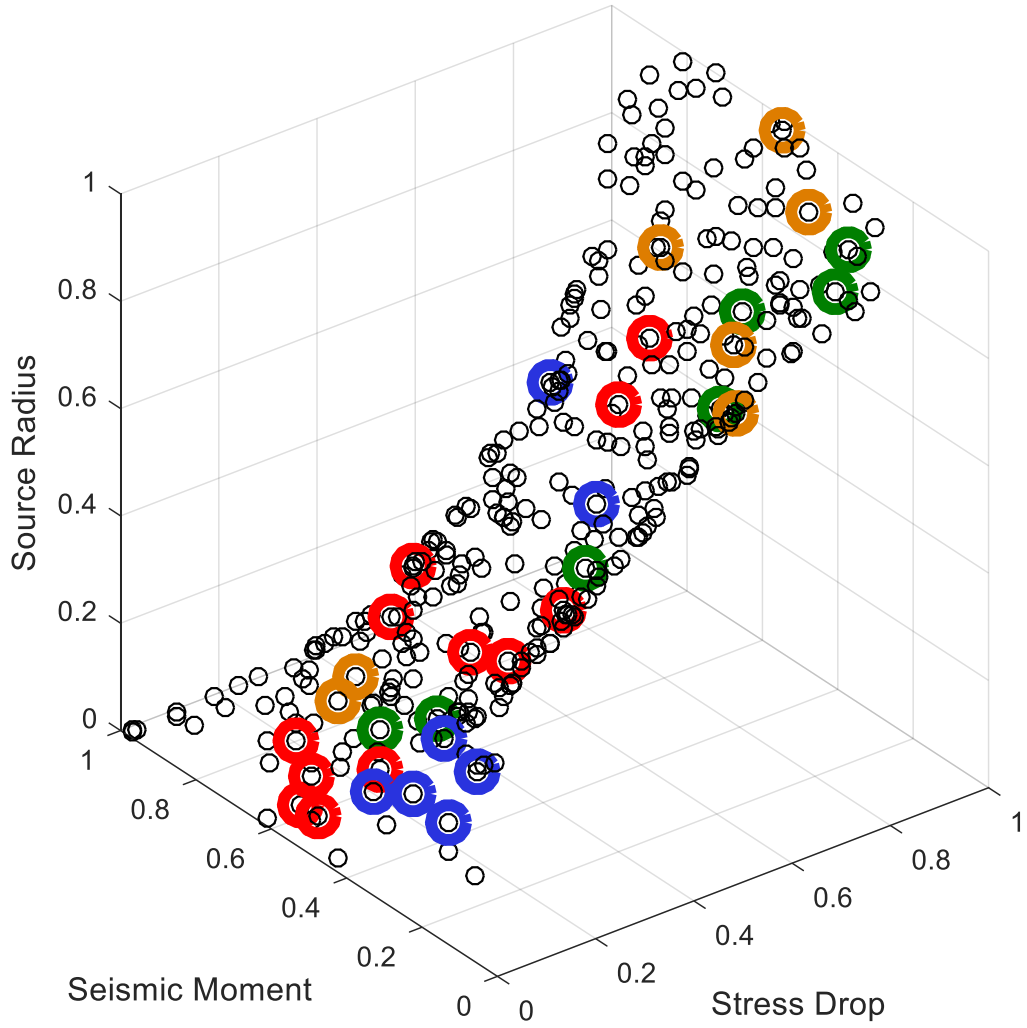
4 families the most linked clusters (LD<0.2, N>6) in XYZ coordinates (colored circles) plotted in 3D Spectral Parameter Space (Sd, R, M_0)





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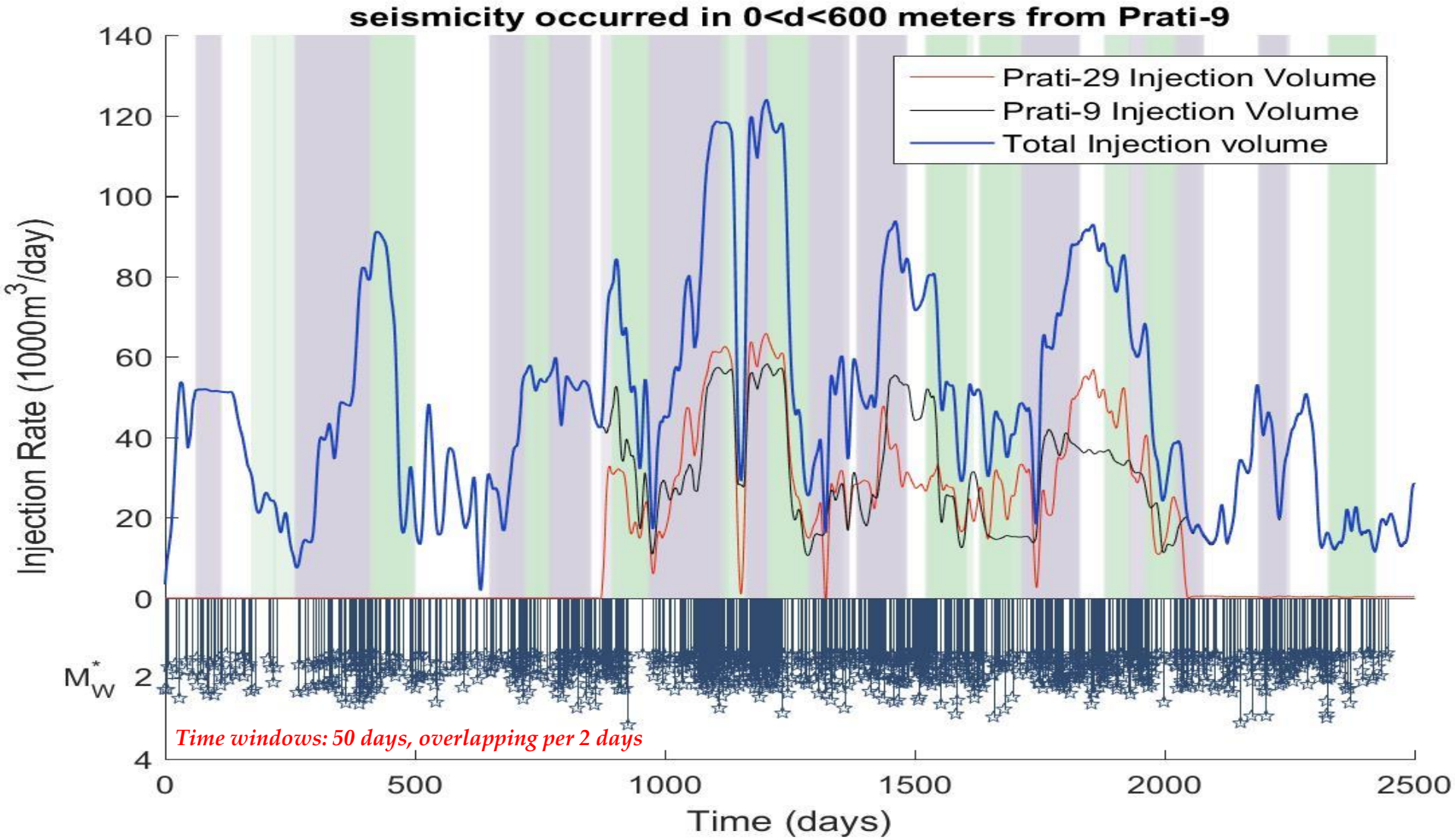
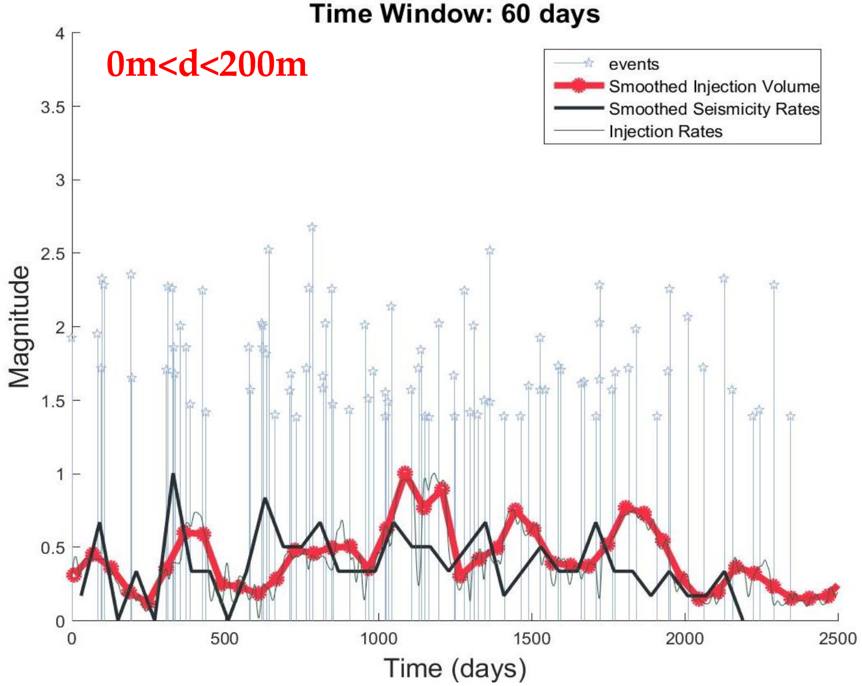
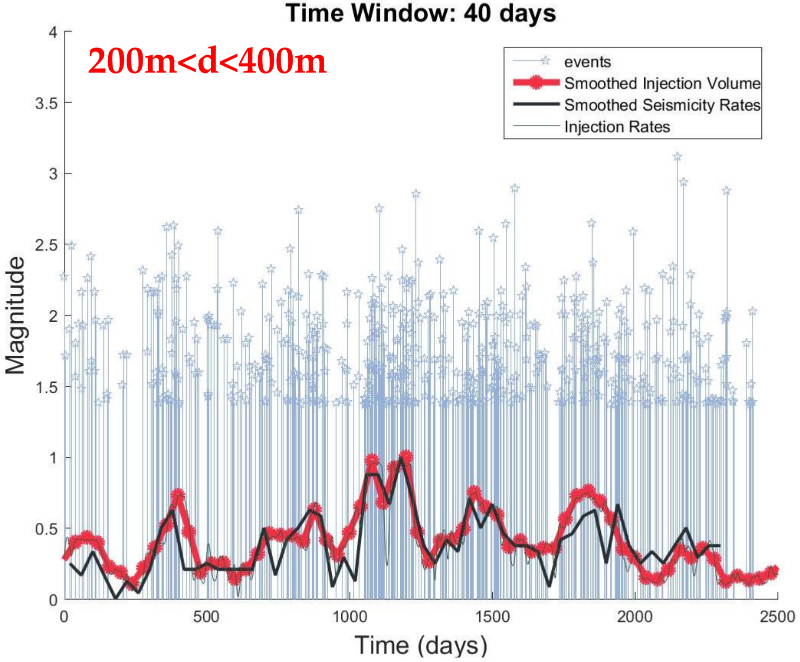
Correlation Analysis Results

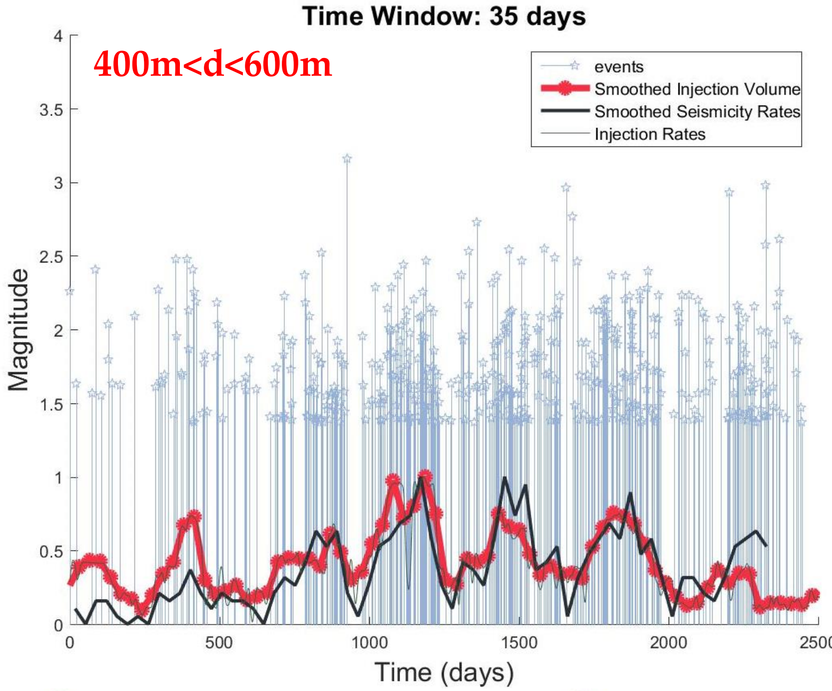
Correlation Analysis

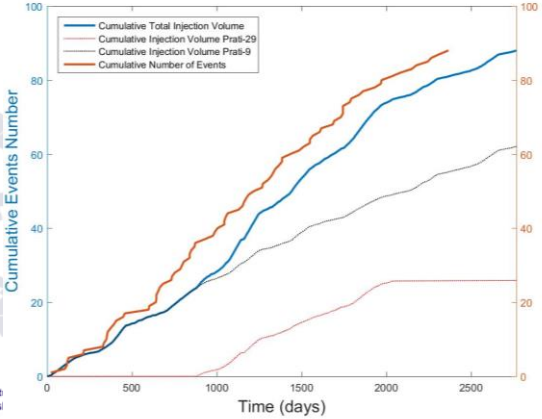


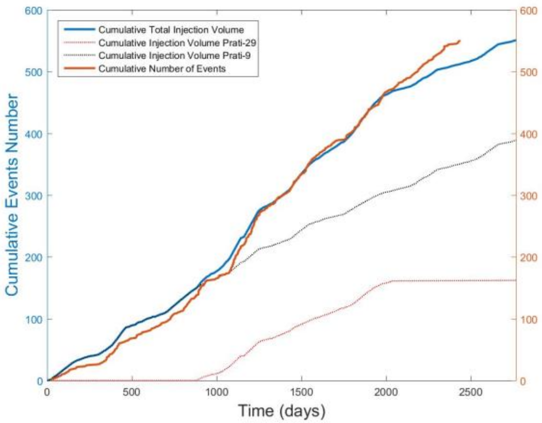
Correlation Analysis

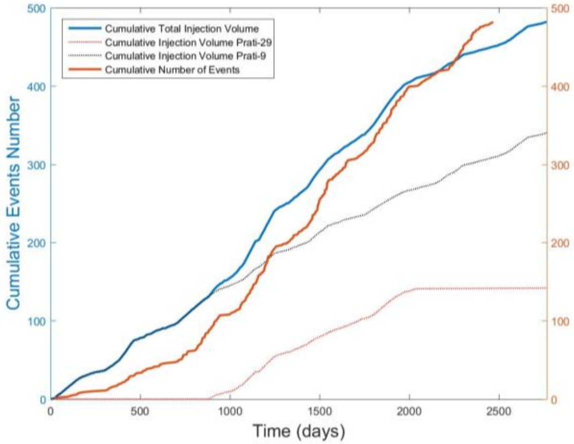




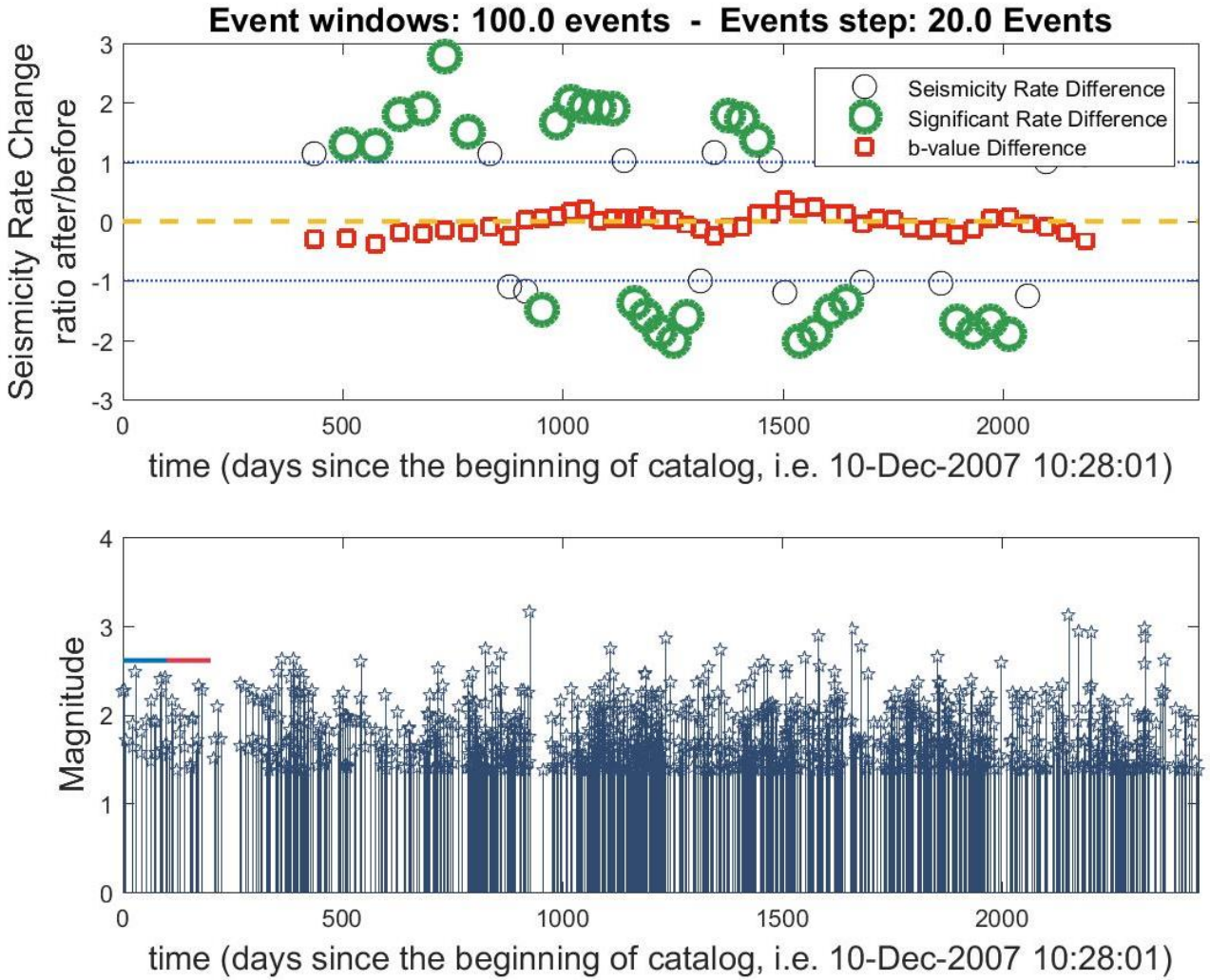




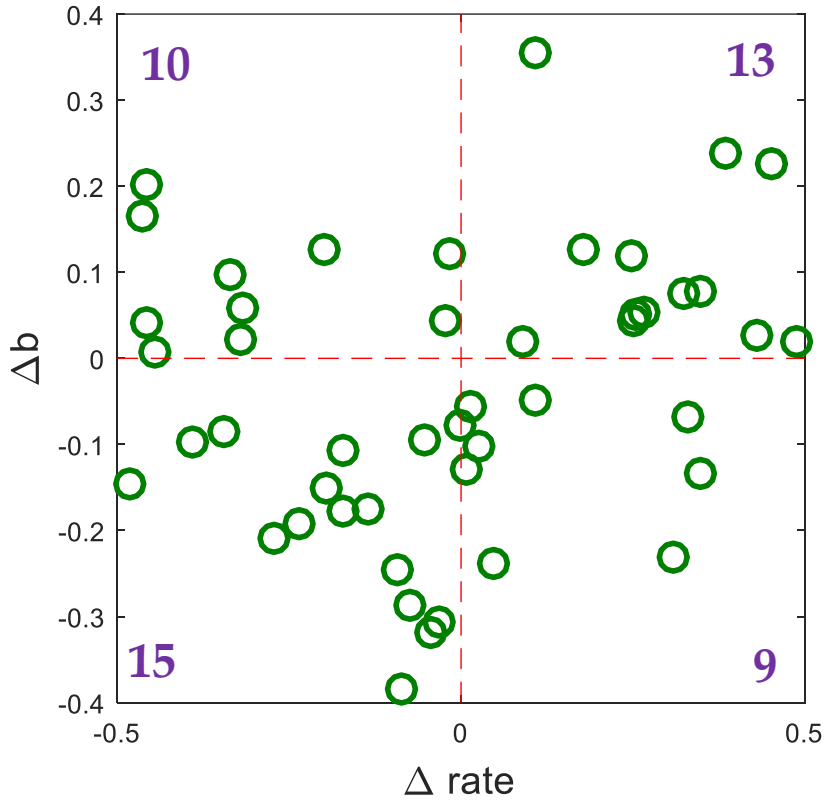




b-value Analysis



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 > 200m from Prati-9
- No clear influence of injection on b-values was detected

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