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Supporting Information for

High injection rates counteract formation of far-reaching fluid migration pathways at The Geysers geothermal field

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Introduction

Text S1 presents briefly the transformation to equivalent dimension technique. This transformation was applied to eight parameters that represented seismic events in calculations of the degree of disordering of sources, *ZZ*. *ZZ* was determined by distances between the events seen as points in 8D space of these parameters. *ZZ* could not be evaluated from original values of these parameters because these parameters were not comparable and five of them did not have the Euclidean metric. The transformation to equivalent dimensions is suited for such problems. After transformation any set of parameters becomes comparable and the parameter space metric becomes Euclidean. The text S1 presents the problem, provides the assumptions of the transformation, defines equivalent dimensions, presents their properties and the algorithm of the transformation. The address of the web page from where the MATLAB codes of the transformation can be downloaded is also provided.

Text S1. Summary of the transformation to equivalent dimension technique (Lasocki, 2014)

Parameters of Seismic Events

- Source parameters: t, lat, lon, $depth$, M, $[M_{i,j}]$, E_s, $\Delta\sigma$, r_0 etc.
- Derived from source parameters of two or more events e.g.: interevent time - τ, distance between this and the main shock - r, etc.

- Other having unambiguous association with seismic events e.g.
  - Parameters of the environment in which the event occurs: e_1, e_2, e_3
  - Parameters of inducing technological activity for anthropogenic seismicity: l_1, l_2, l_3 ...
  - …………………………………

A seismic event ≡ A point in a parameter space e.g. : $\mathbf{X}= [t, lat, lon, depth, M, [M_{i,j}], E_s$ $\Delta\sigma, r_0, \ldots, \tau, r, \ldots, e_1, e_2, e_3, \ldots, l_1, l_2, l_3, \ldots, \ldots]$

Problem: Parameters of seismic events are not comparable and may have non-Euclidean metric.

Equivalent dimensions – Assumptions:

- Let seismic events be represented by the set of parameters X_k, k=1,..,p,. The population of these events is fully characterized by the probabilistic distributions of the parameters $F(X_k)$, k=1,..,p.
- Two intervals of the parameter values, $[x_{k,i},x_{k,j}]$, $[x_{l,s},x_{l,t}]$ are equivalent if $\mathrm{Prob}(X_k \in [x_{k,i},x_{k,j}]) = \mathrm{Prob}(X_l \in [x_{l,s},x_{l,t}])$.
- The parameters X_k, k=1,..,p, are continues random variables.

Equivalent dimension – Definition: The equivalent dimension of X is $U=F(X)$, where $F(X)$ is the cumulative distribution of X

Properties

- Every U is uniformly distributed in [0,1]
- $\{U_{i=1,..p}\}$ has Euclidean metric
- The distance between the two seismic events, i, j , is

$$d(i,j) = \sqrt{\sum_{k=1}^{p}[U_k(i) - U_k(j)]^2}$$

Technique

- The probabilistic models for earthquake parameters, $F(X_k)$, are in general not known.
- If the earthquakes' data are a representative sample of size n, replace $F(X_k)$, k=1,..,p with their data-driven, kernel estimators (Silverman, 1986):

$$\hat{F}_X(x|\{x_i, n\}) = \frac{1}{n}\sum_{i=1}^{n}\Phi\left(\frac{x - x_i}{\lambda_i h}\right)$$

where: $\Phi(u)$ is the cumulative distribution function of the standard normal distribution *h* is the common smoothing factor e.g. the solution of the equation (Kijko, et al., 2001):

$$\sum_{i,j}\left\{2^{-0.5}\left[\frac{\left(x_i-x_j\right)^2}{2h^2}-1\right]exp\left[-\frac{\left(x_i-x_j\right)^2}{4h^2}\right]-2\left[\frac{\left(x_i-x_j\right)^2}{h^2}-1\right]exp\left[-\frac{\left(x_i-x_j\right)^2}{2h^2}\right]\right\} = 2n$$

λ_i are the local bandwidth factors e.g.: (Orlecka-Sikora & Lasocki, 2005)

$$\lambda_i = \left[\frac{\hat{f}^*\left(x_i|\{x_j,n\}\right)}{g}\right]^{-0.5}$$

$$\hat{f}^*\left(x_i|\{x_j,n\}\right) = \frac{1}{\sqrt{2\pi}hn}\sum_{j=1}^{n} exp\left[-\frac{\left(x_i-x_j\right)^2}{2h^2}\right] \qquad g = \left[\prod_{i=1}^{n}\hat{f}^*\left(x_i|\{x_j,n\}\right)\right]^{\frac{1}{n}}$$

The MATLAB toolbox with codes for equivalent dimension transformation can be downloaded from https://git.plgrid.pl/projects/EA/repos/sera-applications/browse