Structure of Motifs in Seismic Networks

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General outline

Seismic Networks

- Earthquakes Data available online
- Building the Seismic Network

Network Analysis

- Connectivity
- Motifs

Concluding remarks & outlook

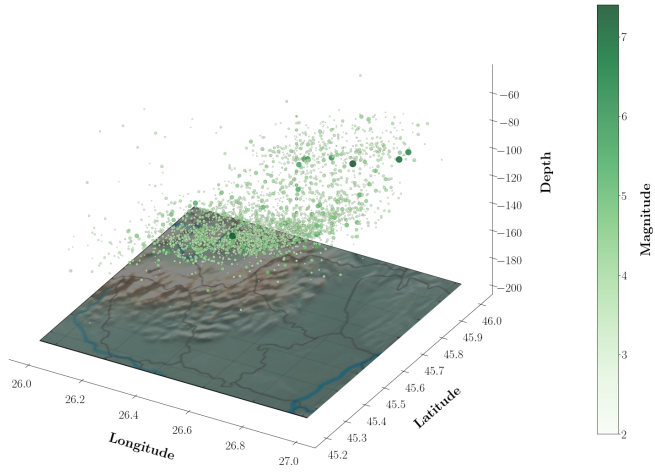
Seismic Networks

Building Seismic Networks from Available Data for Regions around the Globe

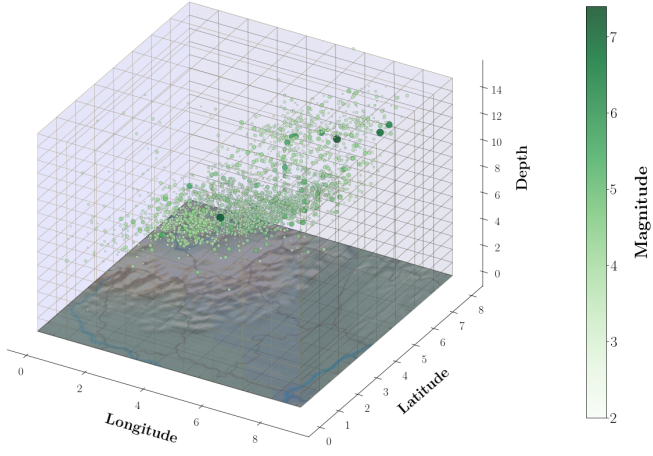
Earthquakes Databases

Seismic Databases				
Seismic Zone	Timeframe	Latitude	Longitude	Depth
Romania	0984-01-01	43.594°N	20.1°E	0
	2021-02-28	48.23°N	26.14°E	218.4
California(USA)	1932-01-02	32°N	-114°W	0
	2020-12-31	37°N	-122°W	51.1
Italy	1986-01-01	30.61°N	-6.08°W	0
	2020-12-31	47.998°N	36.02°E	644.4
Japan	1919-01-11	17.41°N	114.78°E	0
	2019-08-31	54.97°N	160.17°E	698.4

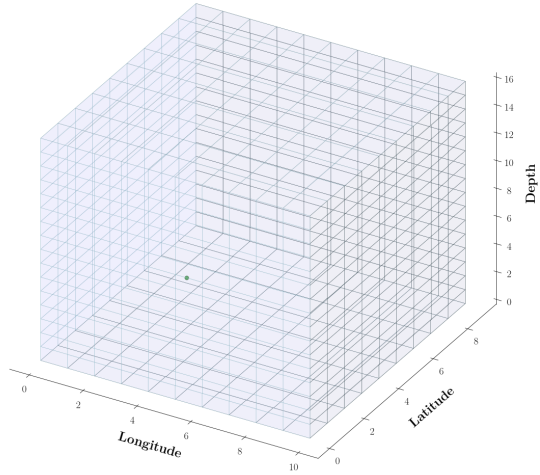
Visualizing the Seismic Region



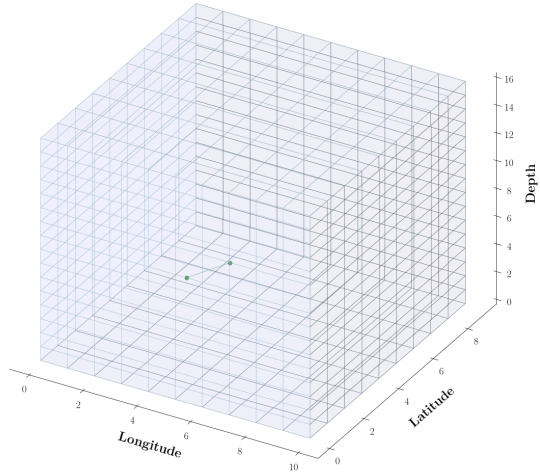
Splitting the region into cubes



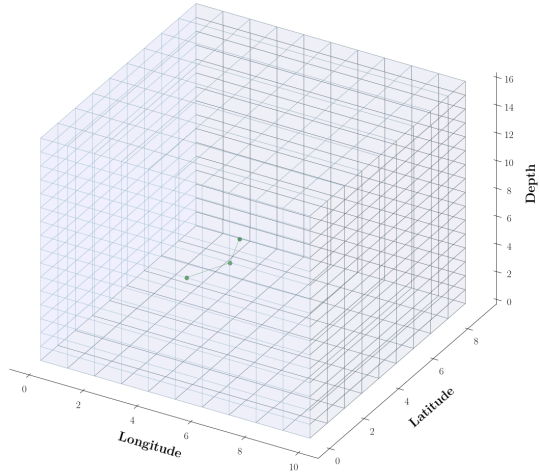
Building the network



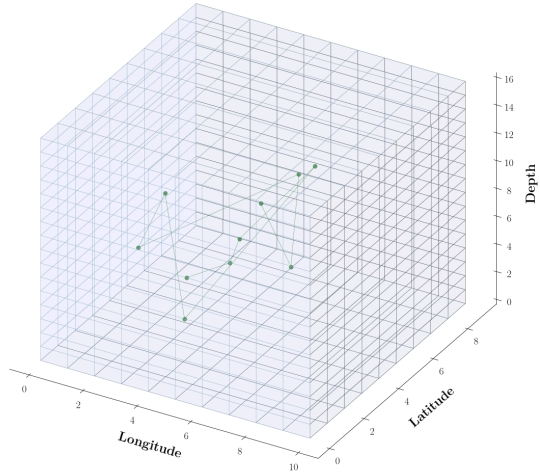
Vrancea Earthquakes: building the network. First earthquake on the list



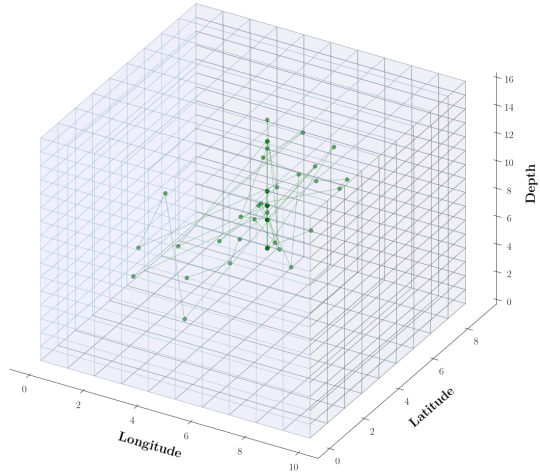
Vrancea Earthquakes: building the network. Two earthquakes



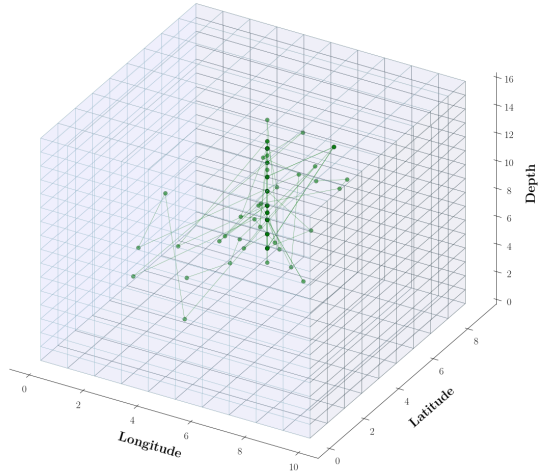
Vrancea Earthquakes: building the network. Three earthquakes



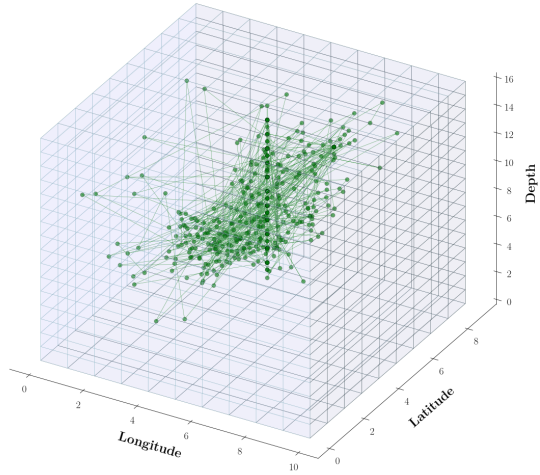
Vrancea Earthquakes: building the network. 10 earthquakes



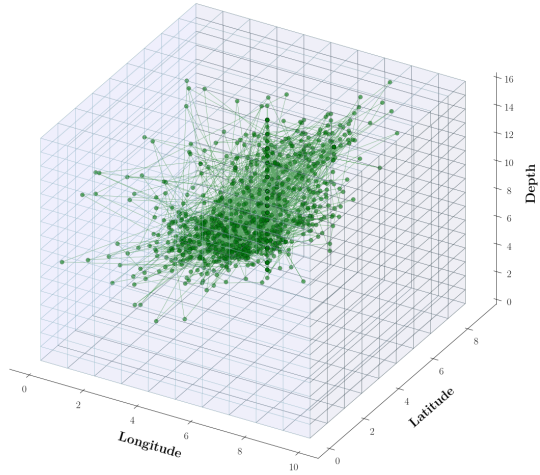
Vrancea Earthquakes: building the network. 50 earthquakes



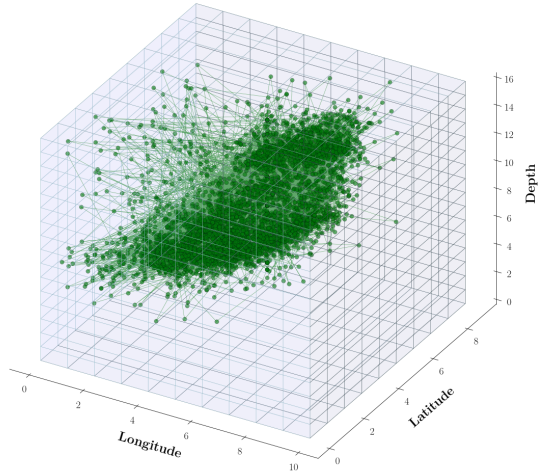
Vrancea Earthquakes: building the network. 100 earthquakes



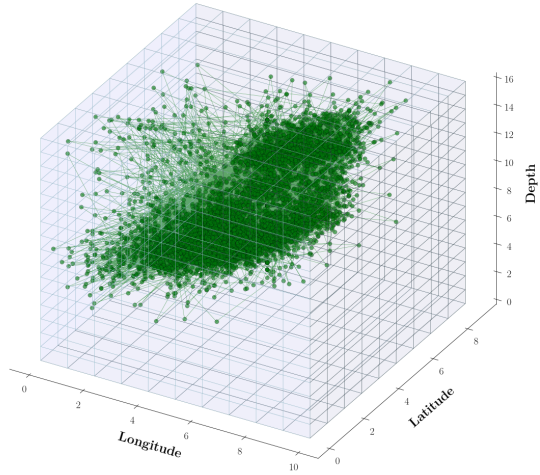
Vrancea Earthquakes: building the network. 500 earthquakes



Vrancea Earthquakes: building the network. 1000 earthquakes

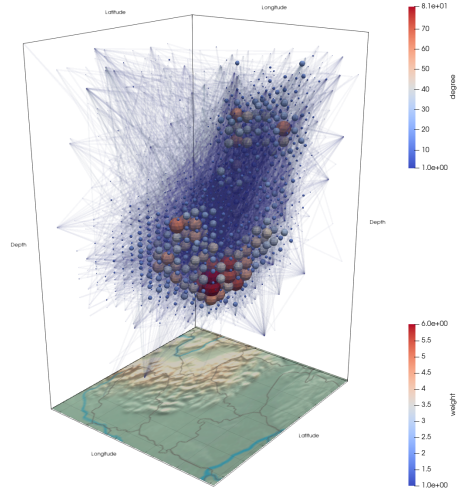


Vrancea Earthquakes: building the network. 5000 earthquakes



Vrancea Seismic Network. 7673 earthquakes

Creating the nodes and edges



Vrancea Earthquakes: building the network. 7673 earthquakes in a network with 1692 nodes and 7423 edges

Network Analysis

Scale-free Networks and their Motifs

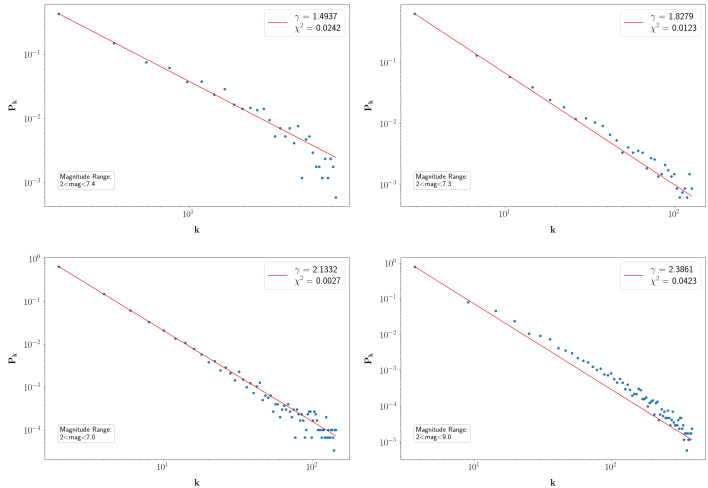
Connectivity: the degree of the network's nodes

In scale-free networks that evolve, the systems that they represent seem to be auto-organizing in a state described by a connectivity distribution that follows a power law.

$$P(k) \sim k^{-\gamma}, \quad \gamma = [1, 3]$$

While the network evolves, a new node is more likely to connect to existing nodes that have high connectivity (preferential attachment)

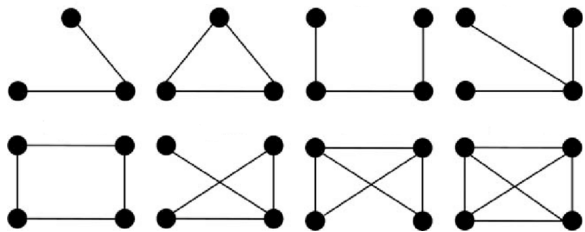
Connectivity: seismic networks are scale-free



Connectivity Distribution in different seismic regions: Vrancea (top left), California (top right), Italy (bottom left), Japan (bottom right)

Motifs: a measure of identifying hidden structures

Network motifs are sub-graphs that repeat themselves in a specific network or even among various networks.



3 and 4 nodes motifs

Each of these sub-graphs, defined by a particular pattern of interactions between vertices, may reflect a framework in which particular functions are achieved efficiently.

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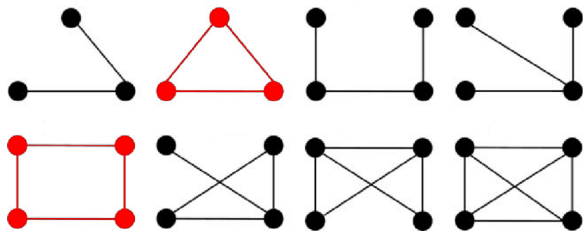

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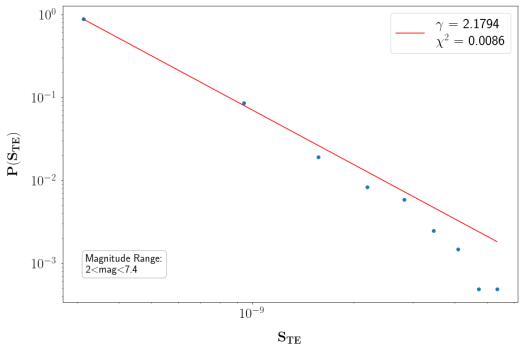
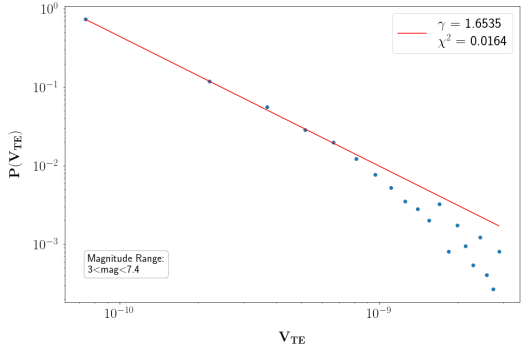
Vrancea motifs statistics

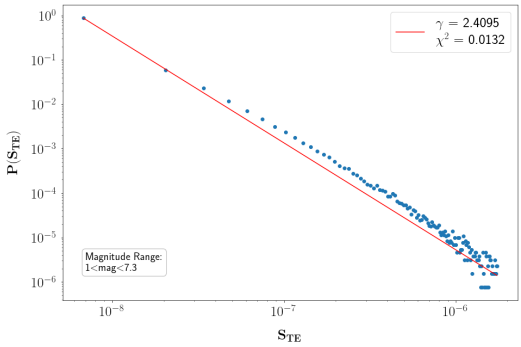


(a) The distribution of triangles area weighted by the total energy released in motif in Vrancea region. It resembles a scale-free distribution with $\gamma = 2.1794$

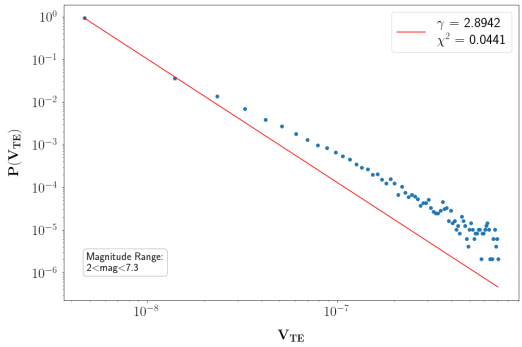


(b) The distribution of tetrahedrons volumes weighted by the total energy released in motif in Vrancea region. It resembles a scale-free distribution with $\gamma = 1.6535$

California motifs statistics

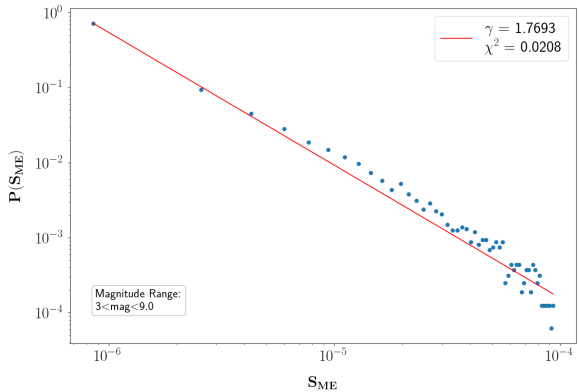


(a) The distribution of triangles area weighted by the total energy released in motif in California region. It resembles a scale-free distribution with $\gamma = 2.4095$



(b) The distribution of tetrahedrons volumes weighted by the total energy released in motif in California region. It resembles a scale-free distribution with $\gamma = 2.8942$

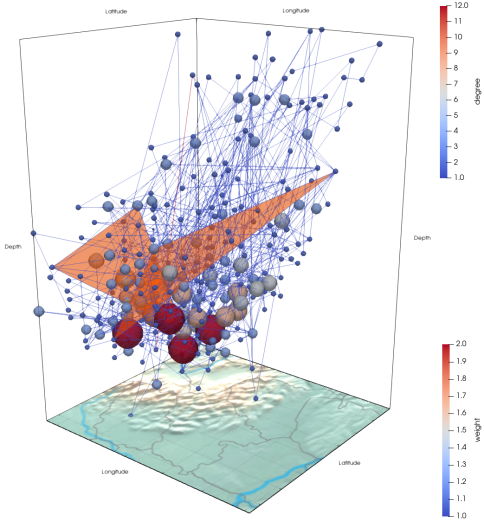
Japan motifs statistics



The distribution of triangles area weighted by the mean energy released in motif in Japan region.
It resembles a scale-free distribution with $\gamma = 1.7693$

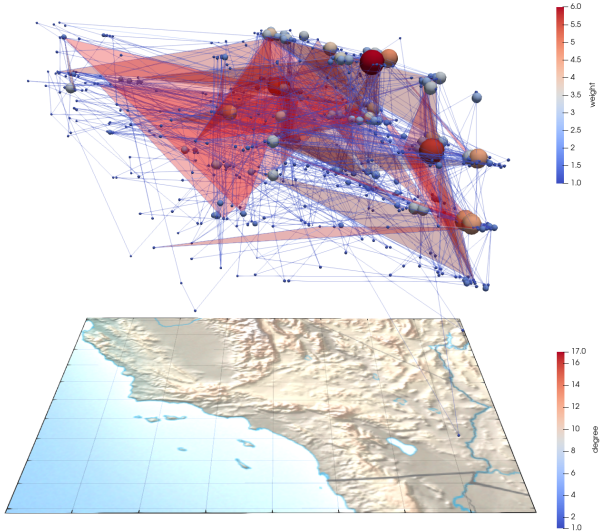
Visualization

Scale-free Networks and their Motifs



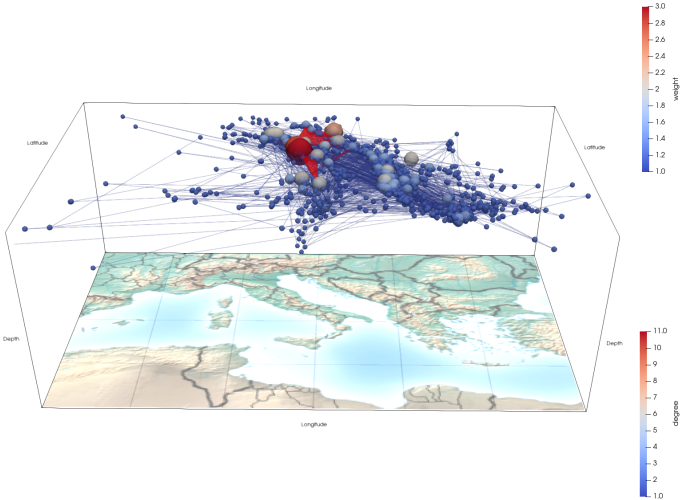
Seismic Network for Vrancea Earthquakes with Magnitudes Larger than 4. *Unpublished

- 385 earthquakes
- in 264 nodes with 381 edges
- and 3 triangles
- connectivity varies between [1,13]
- edge weight varies between [1,2]



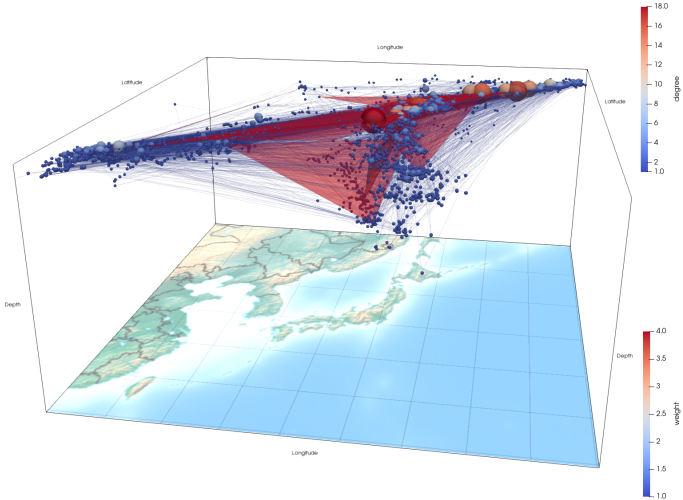
Seismic Network for California Earthquakes with Magnitudes Larger than 4. *Unpublished

- 1134 earthquakes
- in 726 nodes with 1063 edges
- and 45 triangles
- connectivity varies between [1,17]
- edge weight varies between [1,6]



Seismic Network for Italy Earthquakes with Magnitudes Larger than 4. *Unpublished

- 1560 earthquakes
- in 1389 nodes with 1528 edges
- and 16 triangles
- degree varies between [1,11]
- edge weight varies between [1,3]



Seismic Network for Japan Earthquakes with Magnitudes Larger than 5. *Unpublished

- 4960 earthquakes
- in 4361 nodes 4910 edges
- and 48 triangles
- degree varies between [1,18]
- edge weight varies between [1,4]

Concluding remarks & outlook

Conclusions:

- Connectivity: the scale-free like distribution of connectivity enforces the idea of criticality and self-organization in seismic regions.
- Motifs:
  - the scale-free nature of motifs distribution may indicate intrinsic interaction between blocks of earth where earthquakes occur.
  - the coefficient of γ exponent may be an indicator that different regions behave in the same way.

Further studies:

- Identifying of plate tectonics interaction
- Building networks of different characteristics
- Applying more network measures, such as communities discovery

Thank you for your attention!