Monitoring the Measures for Earthquake Networks Between Main Shocks in Greece

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Summary

Monitoring of complex earthquake networks is performed in Greece and surrounding area, aiming to identify the periods when these networks exhibit distinct evolution between the 21 main shocks ($M \geq 6.0$) occurrence, during 1999 - 2015. The study area was divided into 17 appropriately defined seismic zones, considered as nodes. Their connections are given by the significant Pearson correlation computed on the time series of seismic activity of the corresponding nodes. The earthquake networks are formed on sliding windows of 90 days for each of the 20 pairs of main shocks and the values of 9 network measures on each sliding window are computed. To assess whether the values of network measures are statistically significant, the construction of B randomized networks is performed. The monitoring of network measures revealed that the values of network measures for the original networks differ from the corresponding values for random networks in the last time interval, shortly before the main shocks indicating the distinct network structure.

Study area and data

The seismic catalog was compiled in the Geophysics Department of the Aristotle University of Thessaloniki (http://geophysics.geo.auth.gr/ss/). Crustal earthquakes (focal depth less than 50 Km) that occurred during 1999-2017 with $M \geq 3.0$ are only considered so that the condition of the catalog completeness is fulfilled.

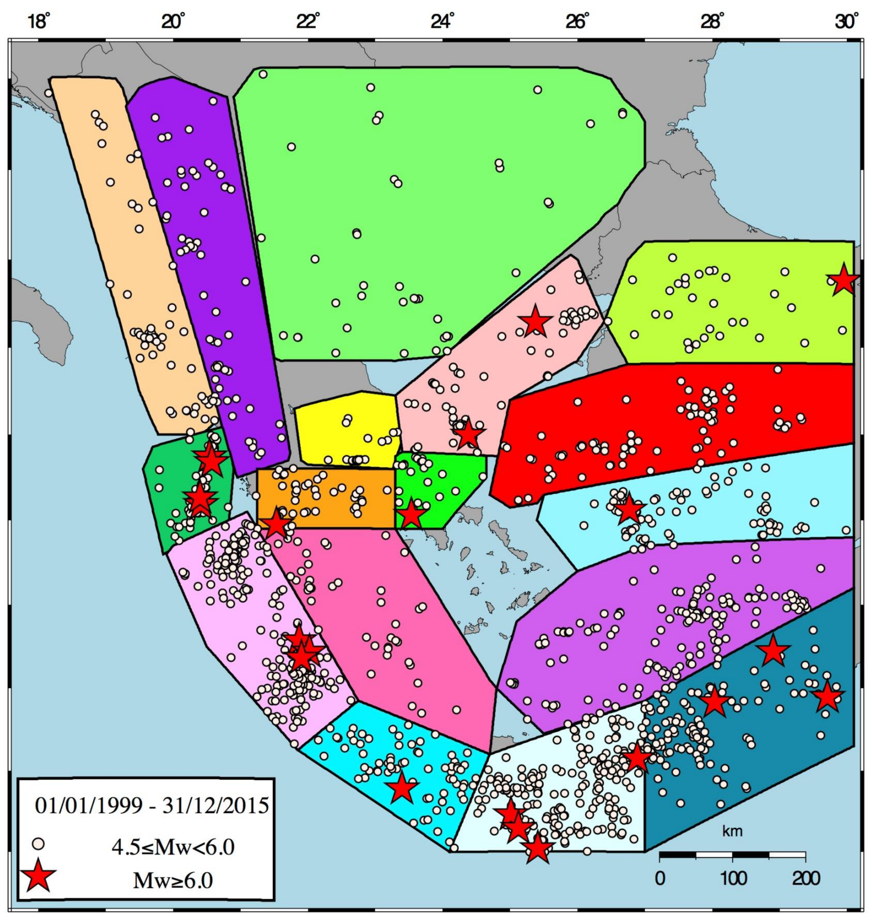

Figure 1. Epicentral distribution of the 21 strong earthquakes with M≥6.0 that occurred between 1999-2015 in the broader area of Greece, divided in 17 seismic zones.

Building the earthquake networks

Nodes: Division of the study area into subareas represented by the seismic zones.
Connections: The connections are given by the significant correlation of the seismic activity in two nodes.
Time series: The observed variables of the time series are either the number of earthquakes or the cumulative seismic moment within each seismic zone.

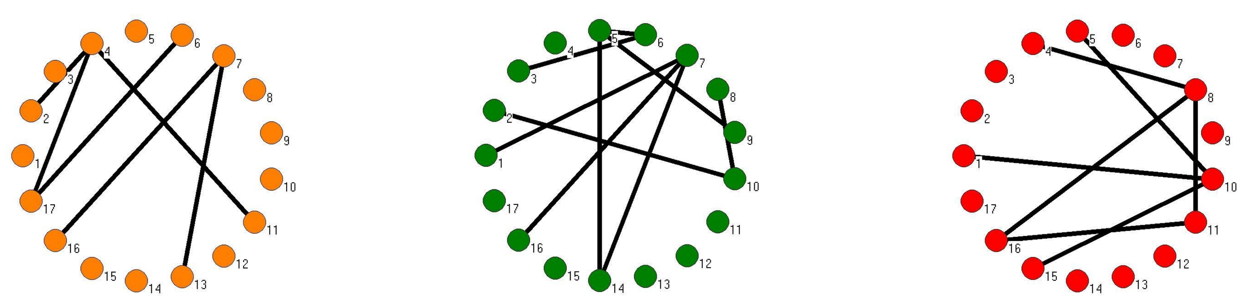

Figure 2. Evolution of earthquake network structure 720 days (top left), 360 days (top right), 90 days (bottom) before the main shock of 14 February 2008.

Network measures

- ❑ Average degree or strength
- ❑ Clustering coefficient
- ❑ Characteristic path length
- ❑ Global efficiency
- ❑ Eigenvector centrality
- ❑ Assortativity
- ❑ Betweenness centrality
- ❑ Diameter
- ❑ Eccentricity

Methodology

- ❑ The earthquake networks are formed on sliding windows of 90 days for each of the 20 pairs of main shocks and the values of 9 network measures on each sliding window are computed.
- ❑ To assess whether the values of network measures on the earthquake networks are statistically significant the construction of $B = 100$ randomized networks is performed.

Methods for network randomization

- ❑ **RNavestr**, on weighted connections, based on network connections randomization that preserves the total strength.
- ❑ **RNnoddeg**, on binary connections, based on network connections randomization that preserves the degree of each node.
- ❑ **RNpoisson**, on binary connections, based on network connections randomization that preserves the average degree.
- ❑ **RTSweight**, on weighted connections, based on time series randomization, from realization of IAAFT surrogates.
- ❑ **RTSbinthr**, on binary connections, based on time series randomization, from realization of IAAFT surrogates that the same threshold criterion as original networks is considered.
- ❑ **RTSbindeg**, on binary connections, based on time series randomization, from realization of IAAFT surrogates that the same number of connections preserved as original networks.

Significance test

- ❑ If the value of the original network measure does not lie within the range of $B = 100$ random networks, then it is statistically significant ($p - value < 0.05$).
- ❑ The p-value is calculated, and the test decision is reached at the significance level $\alpha = 0.05$. Denoting q_0 the test statistic computed on the original network, and $q_1, \ldots, q_B$ on the B randomized networks (r_0 is the rank of q_0 in the ordered list of $q_0, q_1, \ldots, q_B$), the p-value is:

$$p = \begin{cases} \dfrac{2r_0}{B+1}, & if\ r_0 \leq \dfrac{B+1}{2} \\ \dfrac{2(1-r_0)}{B+1}, & if\ r_0 > \dfrac{B+1}{2} \end{cases}$$

Results

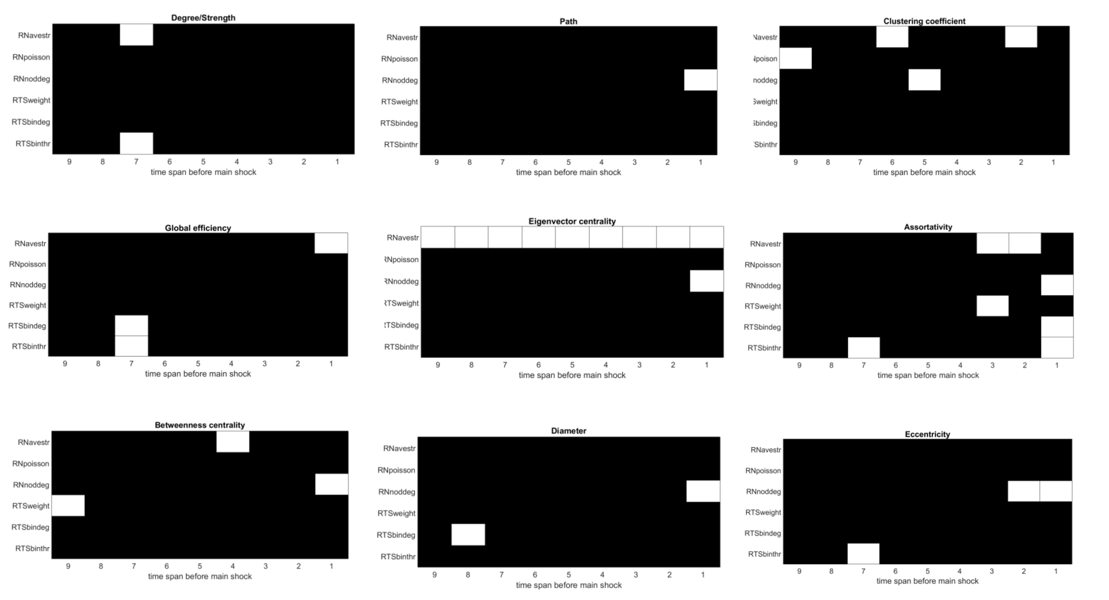

Figure 3. Color map, white for p-value<0.05 and black for p-value>0.05, showing whether the values are statistical significant using the 9 methods of random network generation (row) and for each sliding window before the main shock (column).

Table 1. Number of rejections of the significance test over all network measures for each method (row) and the 9 sliding time spans (column) and the 9 sliding time spans (column) and rate of rejection for each time span.

Methods/ Time spans	9	8	7	6	5	4	3	2	1
RTSbinthr	0	0	5	0	0	0	0	0	1
RTSbindeg	0	1	1	0	0	0	0	0	1
RTSweight	1	0	0	0	0	0	1	0	0
RNnoddeg	0	0	0	0	1	0	0	1	6
RNpoisson	1	0	0	0	0	0	0	0	0
RNavestr	1	1	2	2	1	2	2	3	2
Rate of rejection	0.058	0.039	0.15	0.039	0.039	0.039	0.058	0.078	0.20

Results

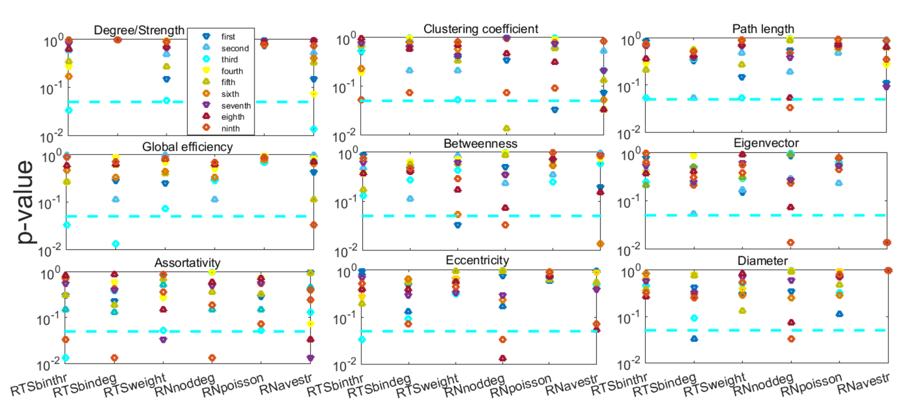

Figure 4. The corresponding p-values (log- scale) of the 9 network measures aforementioned for the main shock of 14 February 2014. The significance level is α=0.05 (dashed line)

Conclusions

- ✓ The monitoring of network measures revealed that the values of network measures for the original networks differ from the corresponding values for random networks, i.e. the values are statistically significant, in the last time interval, shortly before the main shocks indicating the distinct structure of network.
- ✓ The network measures can be regarded as an index of the level of seismicity and may be a useful tool in the study of earthquake networks because their values shortly before the main shocks are statistically significant.

Acknowledgments

This research forms part of the project ‘’Development and Application of Time-Dependent Stochastic Models in selected regions of Greece for assessing the Seismic Hazard” (MIS 5004504), which is implemented through the Operational Program "Human Resources Development, Education and Lifelong Learning" and is co-financed by the European Union (European Social Fund) and Greek national funds.

Ευρωπαϊκή Ένωση
Ευρωπαϊκό Κοινωνικό Ταμείο
Επιχειρησιακό Πρόγραμμα
Ανάπτυξη Ανθρώπινου Δυναμικού,
Εκπαίδευση και Διά Βίου Μάθηση
Ειδική Υπηρεσία Διαχείρισης
Με τη συγχρηματοδότηση της Ελλάδας και της Ευρωπαϊκής Ένωσης
ΕΣΠΑ 2014-2020
ανάπτυξη - εργασία - αλληλεγγύη

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