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«Monitoring Earthquake Network Measures In Aftershock Sequences In Greece»

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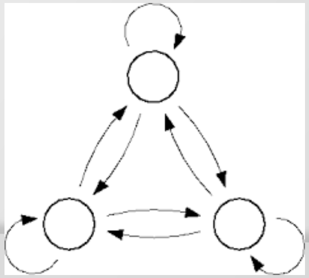
Statistical models and scope of study

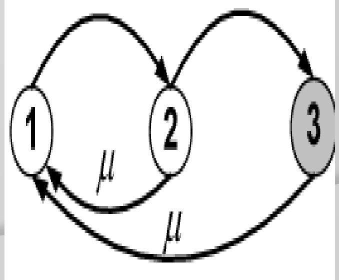
•**Poisson Model →** It **assumes** that the **strong earthquakes** are **independent** in **space** and **time**.

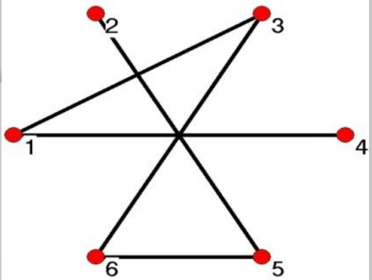
•**Markov Model→** It **assumes** that the **successive earthquakes depend** on **each other** in **space** and **time** (Nava et al. 2005).

•One **approach** for **investigating** the **spatial** and **temporal complexity** of seismicity is effected through the **construction of earthquake networks**, given that **graph theory provides** a framework to **investigate** the **structure** and **dynamics** of a **complex system** (Abe and Suzuki 2004).

•**The scope of this work** is **the monitoring of evolution of 8 network measures for 6 aftershock sequences that occurred during 1999-2015 in Greek territory by strong earthquakes of *M≥6.0***, and the identification of potential patterns in the **distinct evolution** of the **earthquake networks structure before the strongest aftershock**.







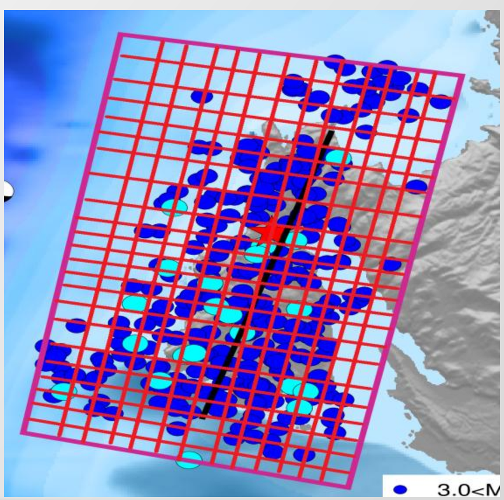
Building the earthquake networks

•The **construction** of **earthquake networks** is **based** on the **Abe and Suzuki** (2004).

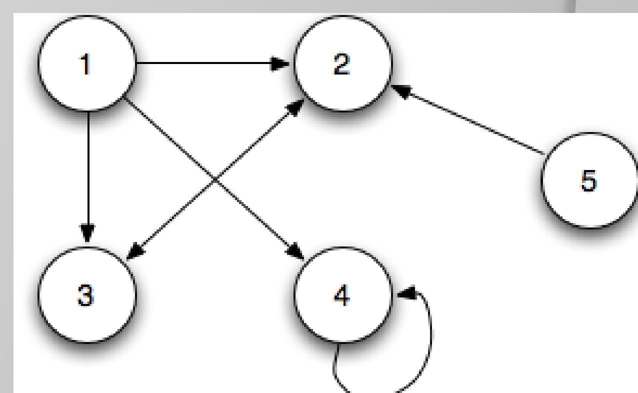
•The **study area** is **divided into *2D* cells** that are **considered** as **nodes** of the **earthquake networks** inside which the earthquakes occurred,

•The **connections** are **given** by the **succession** of **earthquakes**.

Study area → Adjacency matrix (***A***) → Binary Network →



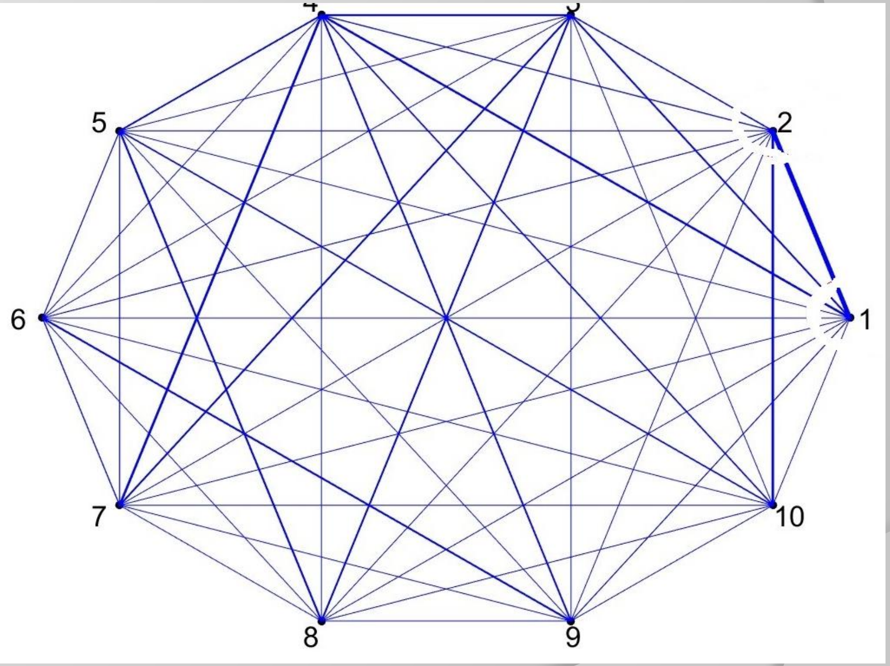
	1	2	3	4	5
1	0	1	1	1	0
2	0	0	1	0	0
3	0	1	0	0	0
4	0	0	0	1	0
5	0	1	0	0	0



Network measures

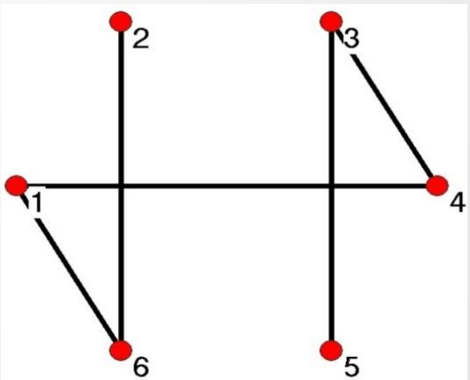
For the **monitoring** of **earthquake network structure** for **aftershock sequences** that examined, the **8 different network** measures that are considered and computed, are:

- **Clustering coefficient**→0.38
- **Characteristic path length**→2.24
- **Global efficiency** →0.45
- **Eigenvector centrality**→0.11
- **Assortativity**→-0.07
- **Betweenness centrality**→2.47
- **Diameter** →2.17
- **Eccentricity**→3.25

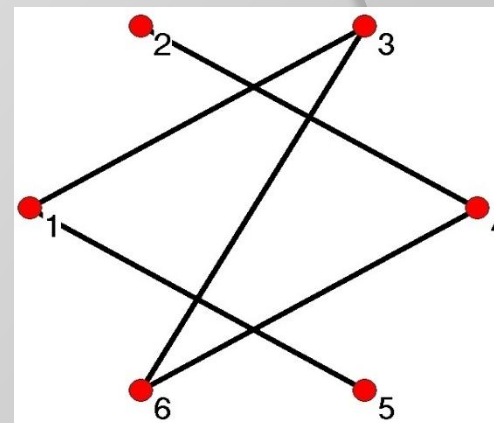


Network randomization

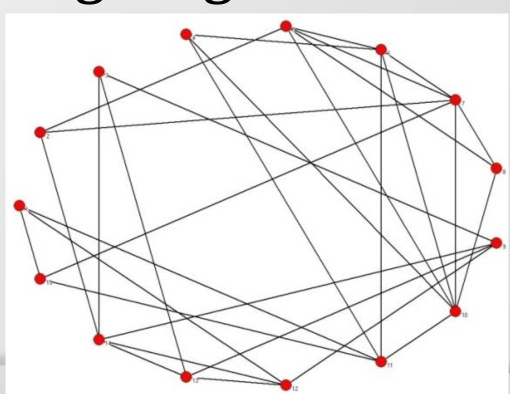
1. A **randomize network requires** the **preservation** of the **degree** of connections of **each node** of the **original** network (Maslov and Sneppen 2002).



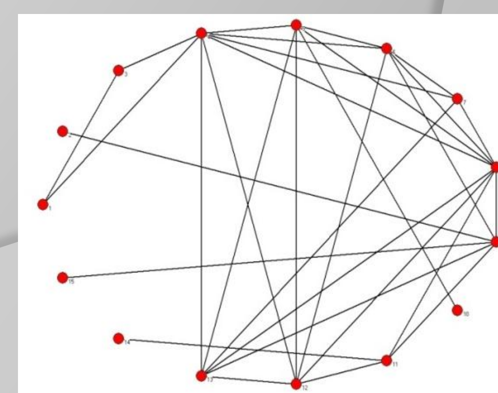
Approach: RNnoddeg



2. In a **different approach**, the **original network** is **built** according to the **Erdős and Rényi** (1959) model with **preset probability** of connections as in the original network, which essentially corresponds to the **preservation** of the **average degree**.



Approach: RNpoisson



Methodology

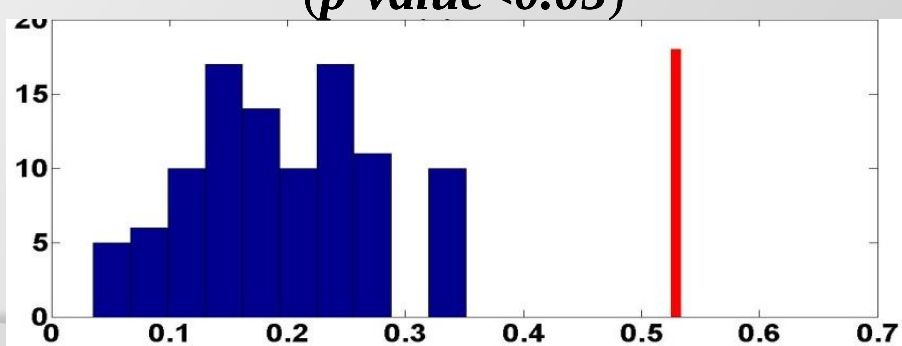
•The **earthquake networks** are **formed on sliding windows of 15 days** for each of the 6 **aftershock sequences** and the values of 8 network measures on each sliding window are computed.

•The **null hypothesis** H_0 that the **network measure val**ues of both the original and ***B=100*** randomized networks are similar (***p-value>0.05***) is considered.

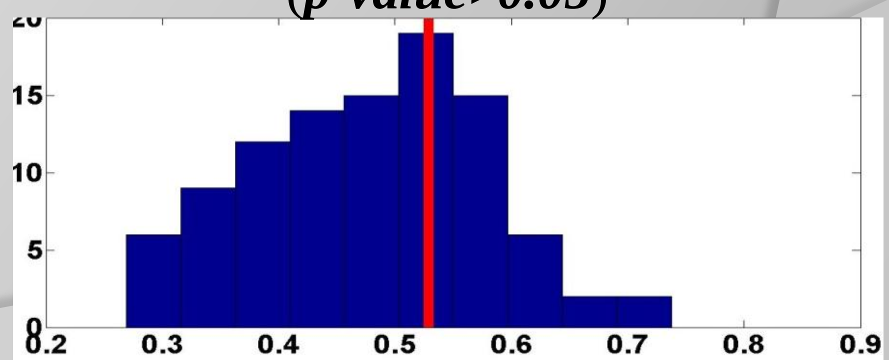
•To **establish** the s**tatistical significance** of the network measures values the test **should reject the null hypothesis H₀** (***p-value<0.05***).

$$\text{p-value}=\begin{cases}\dfrac{2r_0}{B+1}, & \text{if } r_0 \leqslant \dfrac{B+1}{2}\\[2ex] \dfrac{2(1-r_0)}{B+1}, & \text{if } r_0 > \dfrac{B+1}{2}\end{cases}$$

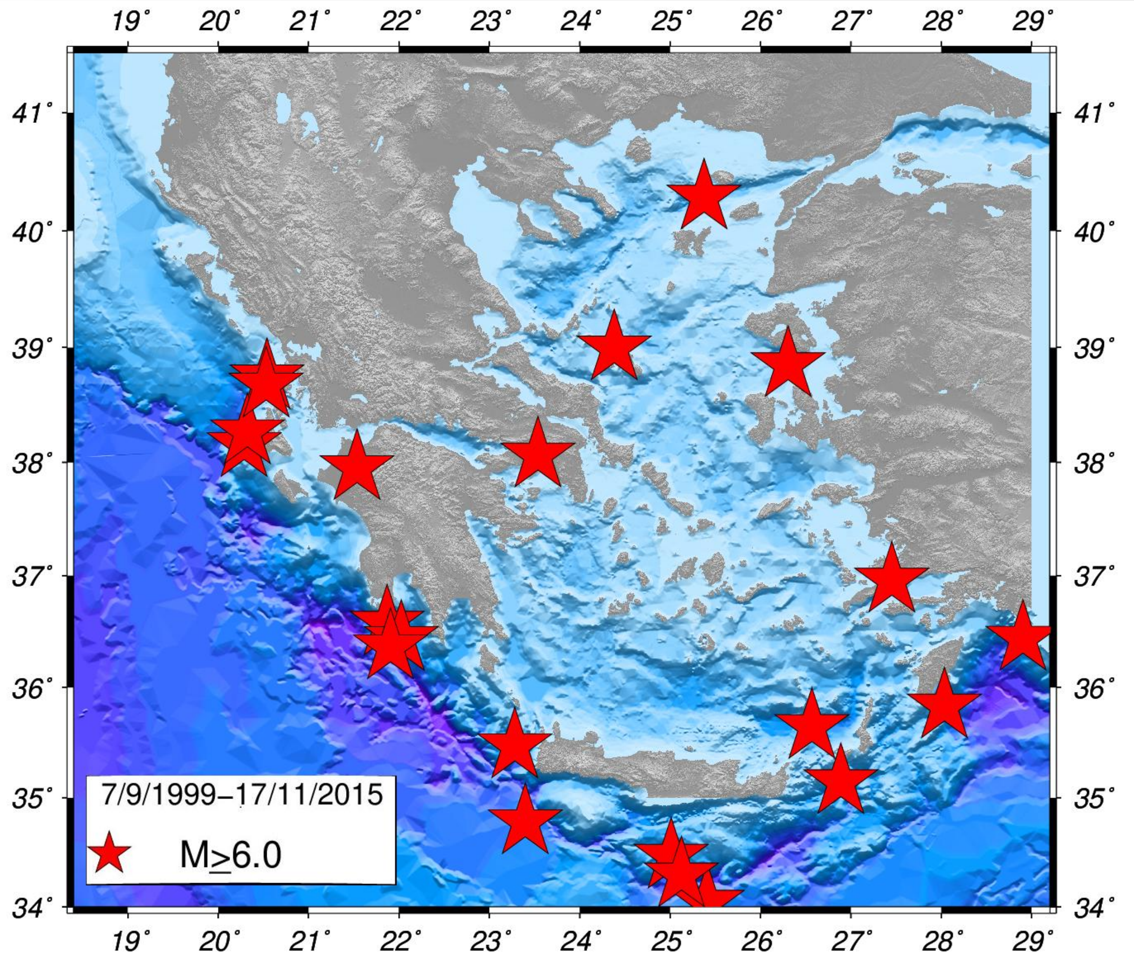
There is statistical significance
(*p-value<0.05*)



There is no statistical significance
(*p-value>0.05*)



Study area and data

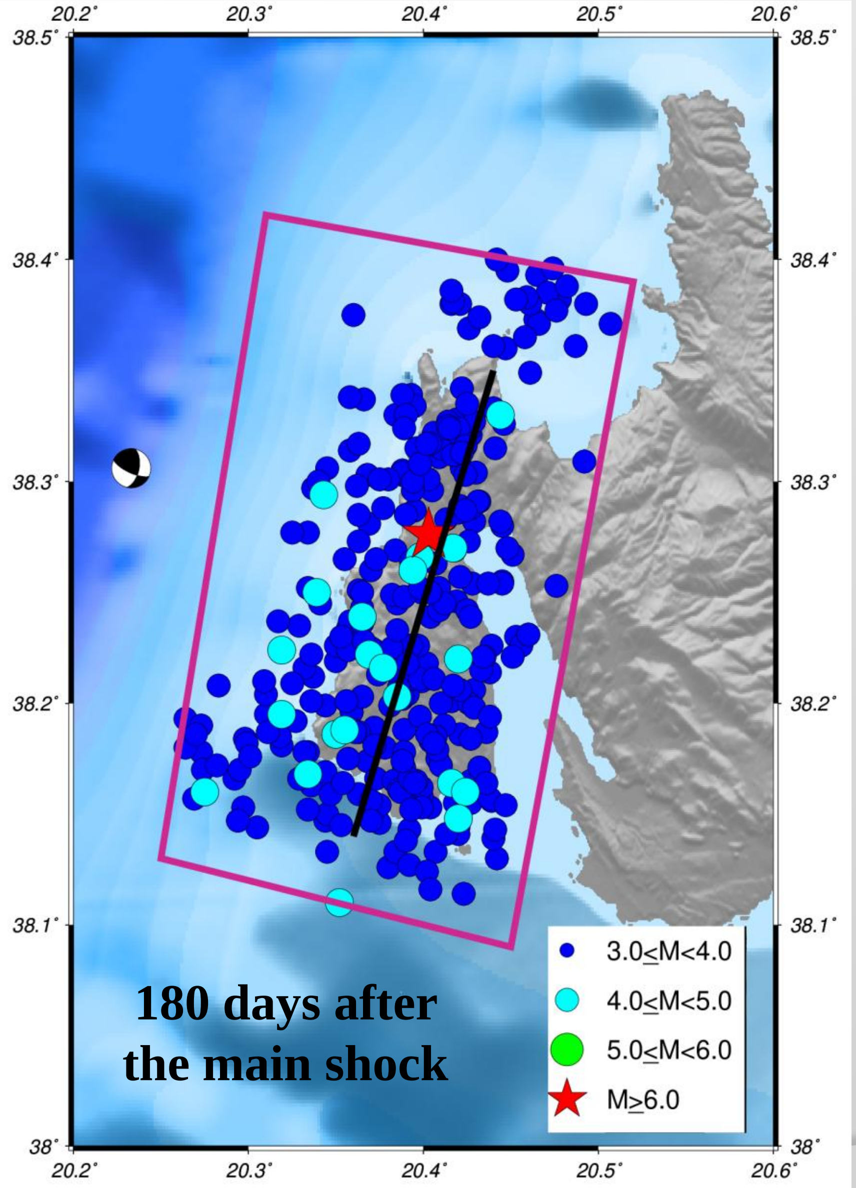


The **seismic catalog** was compiled in the **Geophysics Department** of the **Aristotle University** of **Thessaloniki** (http://geophysics.geo.auth.gr/ss/). **Crustal earthquakes** (focal depth **less than 50 Km**) that occurred during **1999-2015** with ***M*≥6.0** are considered.

We **study six (6) of 22** for which **the interevent period** was sufficiently **long** for the **network measures** to **be robustly computed.**

The **sample data include** comprising **crustal earthquak**es of magnitude ***M≥3.0*** that **occurred** in the **territory** of **Greece during 1999-2015**.

Application-Kefalonia/03-02-2014



•The **seismic sequence** started at the southern part of **Paliki** with the first strong earthquake (**Mw 6.1**, GCMT solution: strike=20°, dip=65° and rake = 177°).

•The **aftershock activity**, particularly earthquakes with ***M>3.0***, is **concentrated** on an **area** of about **13 km long**, starting from the southern coasts of **Paliki** and going to the north.

The other 5 additional study cases.

26/07/2001, *M=6.4*-Skyros

14/02/2008, *M=6*.5 -Methoni

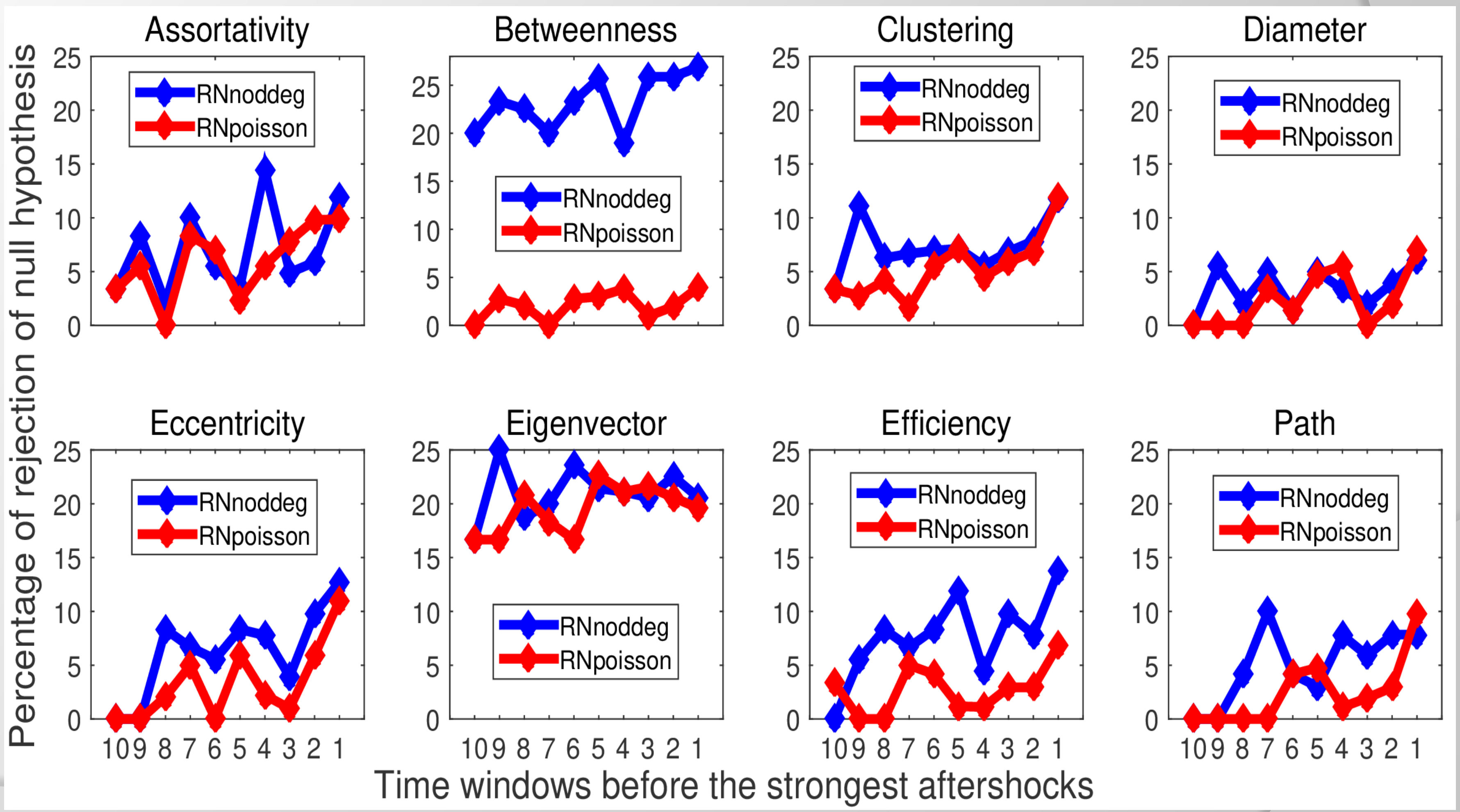
10/06/2012, *M=6.1*-Rhodes

24/05/2014, *M=6.9*-Lemnos

16/04/2015, *M=6.1*-Crete

Application-Results (average of 6 cases)

The **percentage of rejection of H_0**, that **the values for each of the 8 network measures** for the 2 randomization approaches of **original** and **randomized** networks **are similar**, **based on** all **the 6 strongest aftershocks.**



Concluding Remarks

- The **evolution** of **network measures revealed** that the values for the **original earthquake networks are different**, i.e. there is statistical significance, **from the corresponding values for randomized networks** in **the last time interval before the aftershocks**.

- **Clustering coefficient, diameter, eccentricity** and **global efficiency** may be **useful network measures** for **reveal** the **strongest aftershocks**.

- The **application** of the **network theory** is found to be a **powerful tool** for the investigation of **complex phenomena**, such as **seismic activity** as the **changes** in the network structure can reveal certain seismicity behavior **a few days before an aftershock occurrence**.

Acknowledgements and References

The critical reading of the abstract by Prof. **Kugiumtzis** is greatly appreciated. The financial support by the European Union and Greece (Partnership Agreement for the Development Framework 2014-2020) for the project "***Development and application of time-dependent stochastic models in selected regions of Greece for assessing the seismic hazard***" is gratefully acknowledged, **MIS5004504**.

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Thank you for your attention