Renewal Aging Statistical Analysis of Hellenic Seismicity

JULY 8-18 JUILLET 2019 | MONTRÉAL, CANADA
27th IUGG General Assembly
Assemblée Générale de l'UGGI
International Union of Geodesy and Geophysics | Union Géodésique et Géophysique Internationale
IUGG Centennial | 1919-2019 | Centenaire de l'UGGI

SCHOOL OF GEOLOGY AUTH

A. Iliopoulos[1], D. Chorozoglou[1], C. Kourouklas[1], O. Mangira[1] and E. Papadimitriou[1]
(1) Geophysics Department, School of Geology, Aristotle University of Thessaloniki, GR54124 Thessaloniki, Greece
ailiopou@gmail.com, chorozod@geo.auth.gr, ckouroukl@geo.auth.gr, omangira@geo.auth.gr, ritsa@geo.auth.gr

Abstract

The complex turbulent dynamics of seismogenesis in the area of Greece is investigated, applying an alternative approach based on the framework of renewal theory, namely the Renewal Aging Algorithm, to two earthquake interevent (waiting) time series. The data set was extracted from the regional earthquake catalogue compiled by the Geophysics Department of the Aristotle University of Thessaloniki and comprises a complete sample of 576 earthquakes with M≥5.5 occurred during 1911–2017 and 113 earthquakes of M≥6.5, in the period of 1845–2017 (http://geophysics.geo.auth.gr/ss/station_index_en.html). This methodology is efficient for studying persistency and/or intermittent structures in different time scales of Hellenic seismogenesis by qualitatively estimating the amount of memory, corresponding to the ratio between Poisson and non-Poisson critical events. For the application of the Renewal Aging Algorithm time scales corresponding to short- and intermediate- term prediction were considered, namely 2-3 weeks up to 6 years. The results of the statistical analysis reveal transitions from time-homogeneous Poisson to time-homogeneous non-Poisson dynamics and non-homogeneous non-Poisson dynamics, starting from short time scales and considering longer time scales. These results can shed more light to the concept of the irregular seismic cycle hypothesis for the study area. It is worth to be mentioned that these time series are relatively short and therefore additional statistical analysis is required to verify the aforementioned findings.

1a. Renewal aging algorithm

➢ **CreatingAged WT sequences**

a) The aging time t_a is selected and a time window of length t_a is moved along through the time series

b) Considering as starting time window the earthquake occurrence t_n, then the first earthquake k $(k > n)$, occurring after the end of the time window, is found as $t_{k-1} < t_n + t_a < t_k$.

c) The sequence of *aged* WTs $\{\tau_n(t_a)\}$, n=1,2…, is computed, where the *aged* WT equals to $\tau'_n=\tau_n(t_a)=t_k-(t_n+t_a)$.

d) For the original WT sequence: $\psi(t)$, $\Psi(t)$, the young WT histogram (WT-PDF) and the Survival Probability Function (WT-SPF) are computed.

e) The real *aged* WTs are obtained applying the Renewal Aging algorithm to the original WT-SEQ, for a given t_a.

f) The renewal WTs are obtained from the application of random shuffling to the original sequence of WTs.

g) The *renewal aged* WTs are obtained by applying the Renewal Aging algorithm to the renewal sequence generated in the previous step.

h) The WT-PDFs are computed for the two aged WT-SEQs, getting the Real-PDF and Real-SPF and the Renewal-PDF and Renewal-SPF.

1b. Renewal aging algorithm

➢ Compare the three WT-SPFs to infer the amount of memory in the WT-SEQ sequence and its non-Poisson features. Depending on the results of the Renewal Analysis the following conclusions can be drawn.

a) For $\Psi(t,t_a)=\Psi^{Real}(t,t_a)=\Psi^{Renewal}(t,t_a)$, time-homogeneous Poisson process (HPP) is concluded.

b) For $\Psi(t,t_a)<\Psi^{Real}(t,t_a)=\Psi^{Renewal}(t,t_a)$, a Renewal Homogeneous Non-Poisson Process (RNPP) is concluded.

c) Modulation acceleration increases with the ratio between critical non-Poisson events and secondary Poisson events.

d) If $\Psi^{Real}(t,t_a)$ decreases from Renewal Aging $\Psi^{Renewal}(t,t_a)$ to $\Psi(t,t_a)$ as the modulation steadily slows down, then a non-Homogeneous Poisson Process (NHPP) with a random rate modulation generating critical events, is concluded.

e) Very slow modulation has got zero Renewal Aging, implying that $\Psi(t,t_a)=\Psi^{Real}(t,t_a)\neq\Psi^{Renewal}(t,t_a)$.

2a. Results

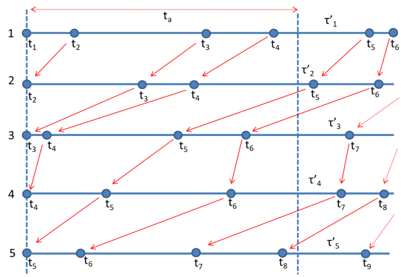

Figure 1. Schematic sketch of the Renewal Aging algorithm. The Renewal Aging algorithm is applied to a single sequence of WTs, corresponding to the first sequence from the top.

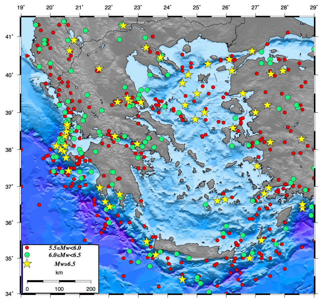

Figure 2. Epicentral distribution of earthquakes with magnitudes and occurrence periods considered in this study.

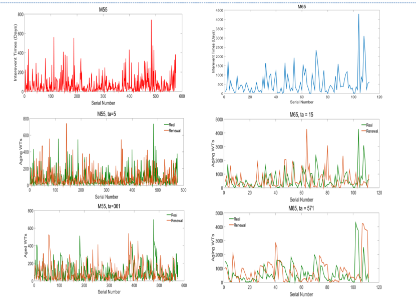

Figure 3. Waiting Times (WT) series for earthquakes with M≥5.5 and M≥6.5 that occurred in the study area since 1911and 1845, respectively. In addition, examples of the respective aged WT sequences are shown generated for t_a =5, 361 (M55-WTs) and t_a=15, 571 (M65-WTs).

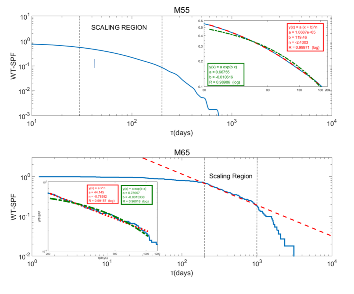

Figure 4. The Survival Functions (WT-SPF) of M55 and M65 WT sequences in log-scale.

2b. Results

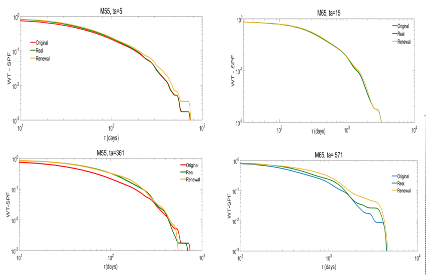

Figure 5. The Survival Functions of M55 and M65 WT sequences in log-scale compared to the respective WT-SPFs of the aged WT sequences generated for t_a =5, 361 (M55-WTs) and t_a=15, 571 (M65-WTs).

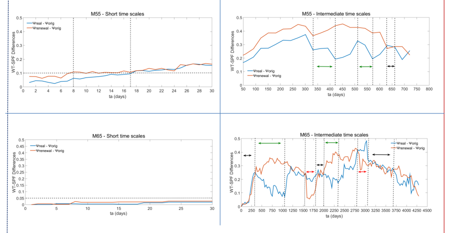

Figure 6. The differences of the WT-SPFs of M55 and M65 WT sequences and their respective aged WT sequences, estimated for short and intermediate time scales.

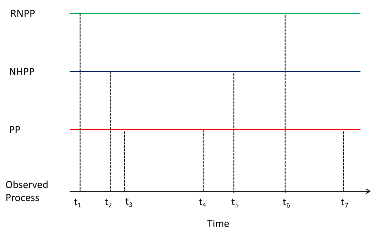

Figure 7. An example of the observed earthquake process as a superposition of three stochastic point processes, namely homogeneous Poisson (HPP), Non-Homogeneous Poisson Process (NHPP) and Non-Poisson model (RNNP).

3. Summary

➢ *For M55-WTs and short-time scales*: For t_a ranging from 1 to 8 days, a time homogeneous Poisson process (HPP), is indicated since $\Psi(t,t_a)=\Psi^{Real}(t,t_a)=\Psi^{Renewal}(t,t_a)$. For t_a ranging from 17 to 30, $\Psi(t,t_a)<\Psi^{Real}(t,t^a)=\Psi R^{enewal}(t,t_a)$, a Renewal time-homogeneous Non-Poisson Process (RNPP) model.

➢ *For M55-WTs and intermediate-time scales*: For t_a range values between 50-330 days the results indicate neither total aging nor complete lack of aging, indicating a system receiving a partial amount of Renewal Aging. This result can be related to a Non-homogeneous Non-Poisson process (NHNPP) with slow modulation or a RNPP model. For larger t_a values, namely 330-420 days and 510-570 days, a significant reduction of Renewal aging appears indicating a NHPP with a random rate modulation generating critical events. For t_a values between 420-510 days and 570-630 days the results indicate a RNPP model.

➢ *For M65-WTs and short-time scales*: A time-homogeneous Poisson Process (HPP), since $\Psi(t,t_a)=\Psi^{Real}(t,t_a)=\Psi^{Renewal}(t,t_a)$.

➢ *For M65-WTs and intermediate-time scales*: Between 30-330 days, the results indicate a RNNP model, since $(t,t_a)<\Psi^{Real}(t,t_a)=\Psi^{Renewal}(t,t_a)$.

Conclusions

The results reveal:

➢ The complex statistical profile of the WT sequences. Different time windows exhibit different statistical profiles and transitions to various statistical processes such as HPP, RNPP, NHPP and NHNPP.

➢ This behavior depends also on the value of the threshold M, since a more homogeneous statistical profile is revealed for M55-WTs and a more erratic for M65-WTs.

➢ The observed WTs of large earthquakes (M ≥ 5.5 and M≥6.5) can be a superposition of these different point processes (an example of this hypothesis is depicted in Fig. 7), which contribute significantly to the total energy and entropy of the time series.

➢ These hidden statistical processes indicate that there is memory beyond Omori's law related to Non-Poissonian nature of WTs between consecutive large earthquakes. This memory corresponds to long-range correlations, is present in intermediate time scales and can be revealed by Renewal Aging analysis.

➢ The seismic hazard greatly changes with time and there is no "one-size-fits-all" stochastic model, but the appropriate choice depends on the specific time window, indicating that a distribution suitable for short WTs does not fit the long interevent times and vice versa.

➢ The results of this study indicate that the generations of mixed time-dependent stochastic models will be more suitable in capturing the complexity of earthquake occurrences.

➢ The inclusion of Renewal Algorithm in statistical analysis of seismic catalogues can provide a deeper comprehension of the earthquake occurrence and can contribute to the seismic hazard assessment.

References

Iliopoulos AC, Pavlos GP, Athanasiu MA. Spatiotemporal Chaos into the Hellenic Seismogenesis: Evidence for a Global Strange Attractor. NPCS 2008; 11: 274-279.
Iliopoulos AC, Pavlos GP. Global Low Dimensional Seismic Chaos in the Hellenic Region. IJBC 2010; 20: 2071-2095.
Iliopoulos AC, Pavlos GP, Papadimitriou EE, Sfiris DS, Athanasiou MA, Tsoutsouras VG. Self Organized Criticality, intermittent turbulence and non-extensivity revealed from seismogenesis in North Aegean area. Int J Bifurc Chaos 2012; 22(9): 1250224.
Iliopoulos A, Chorozoglou D, Kourouklas C, Mangira O, Papadimitriou E, Superstatistics, Complexity and Earthquakes: A Brief Review and Application on Hellenic Seismicity. *accepted in Boll. Geof. Teor. Appl.* 2019.
Mangira O, Kourouklas C, Chorozoglou D, Iliopoulos A, Papadimitriou E. Modeling the earthquake occurrence with time-dependent processes: a brief review. Acta Geophysica 2019; 67(3): 739–752.
Paradisi P, Cesari R, Grigolini P. Superstatistics and renewal critical events. Cent. Eur. J. Phys.2009a;7(3): 421-431.
Votsi I, Limnios N, Papadimitriou E, Tsaklidis G. Earthquake Statistical Analysis through Multi-state Modeling, Mathematics and Statistics Series: Statistical Methods for earthquakes set, Volume 2, WILEY, 2019.

Acknowledgements

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**.

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