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Papadakis G. — Institute for Risk and Disaster Reduction, University College London

Vallianatos F. — Institute for Risk and Disaster Reduction, University College London; Laboratory of Geophysics and Seismology, Technological Educational Institute of Crete

Michas G. — Institute for Risk and Disaster Reduction, University College London

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THE EARTHQUAKE INTERVENT TIME DISTRIBUTION ALONG THE HELLENIC SUBDUCTION ZONE

Papadakis G.[1], Vallianatos F.[1,2] and Michas G.[1]

[1]Institute for Risk and Disaster Reduction, University College London, Gower Street, London, WC1E 6BT, UK (georgios.papadakis.10@ucl.ac.uk)

[2]Laboratory of Geophysics and Seismology, Technological Educational Institute of Crete, Chania, GR 73133, Crete, Greece

Abstract

The Hellenic Subduction Zone (HSZ) is the most seismically active region in Europe (Becker and Meier, 2010). The evolution of such an active region is characterized by complex phenomenology and is expressed through seismicity. Seismicity temporal patterns remain as one of the most important topics in earth sciences. The Weibull distribution has been used as a recurrence time model for large earthquakes (Rikitake, 1976; Rikitake, 1991). Moreover,Hasumi et al. (2009) used the Weibull-log Weibull distribution for the study of the interoccurrence times of earthquakes in Japan.The dataset formed in this study concerns the seismic belt of the HSZ during the period 1976-2009. We use the external seismic sources of shallow earthquakes in the Aegean and the surrounding area (Papaioannou and Papazachos, 2000) along with the updated and extended earthquake catalogue for Greece and adjacent areas (Makropoulos et al., 2012).The application of the Weibull distribution to the interevent times of the formed dataset is analyzed and discussed.

Key words: *HellenicSubduction Zone, Weibull distribution,seismicity*

Περίληψη

Η ελληνική ζώνη υποβύθισης είναι η πιο σεισμική περιοχή της Ευρώπης. Η κατανομή Weibullέχει χρησιμοποιηθεί σαν μοντέλο για την περιγραφή των χρονικών διαστημάτων μεταξύ διαδοχικών σεισμών σε συγκεκριμένες ρηξιγενείς ζώνες (Rikitake, 1976; Rikitake, 1991), καθώς και για την περιγραφή της σεισμικότητας μίας ευρύτερης περιοχής (Hasumietal., 2009). Ταδεδομένα που αναλύουμε σε αυτή την εργασία αφορούν την ελληνική ζώνη υποβύθισης και καλύπτουν την περίοδο 1976-2009. Χρησιμοποιούμε τις σεισμικές πηγές επιφανειακών σεισμών όπως αυτές ορίζονται από τους PapaioannouandPapazachos(2000), καθώς και τονκατάλογο σεισμών των Makropoulosetal. (2012) για την Ελλάδα και τις παρακείμενες περιοχές. Η εφαρμογή της κατανομής Weibullστα χρονικά διαστήματα μεταξύ διαδοχικών σεισμών αναλύεται και περιγράφεται σε αυτή την εργασία.

Λέξεις κλειδιά: *Ελληνική ζώνη υποβύθισης, κατανομή Weibull, σεισμικότητα*

1. Introduction

The eastern Mediterranean region presents a remarkable record of major earthquakes (Ambraseys and Jackson, 1998).The Hellenic Subduction Zone (HSZ) is an active seismic belt (Becker and Meier, 2010; Meier et al., 2004). Many destructive earthquakes have taken place along the HSZ (Papathanasiou et al., 2005; Papazachos and Papazachou, 2003). This high seismic activity is caused by the subduction of the Adriatic continental lithosphere in the north and the Ionian oceanic lithosphere in the south (Royden and Papanikolaou, 2011). The Kephalonia Transform Zone (KTZ) separates the northern part (N.HSZ) of the Hellenic subduction boundary from the southern one (Fig. 1).The evolution of such an active region is characterized by complex phenomenology and is expressed through seismicity.

Seismicity temporal patterns remain as one of the most important topics in earth sciences.Over the past years, much has been written about the distribution of interevent times, which are defined asthe time intervals between successive earthquakes. Various distributions have been used to fit earthquake interevent time statistics (Abaimov et al., 2008). Among them, one of the most recent is proposed by Vallianatoset al., (2012), where the spatiotemporal properties of the 1995 Aigion (Greece) earthquake aftershock sequence were investigated using the concept of Nonextensive Statistical Physics formalism (Tsallis, 1988; Tsallis, 2009). The aforementioned authors conclude that Tsallis entropic term describes very well the observed distributions and the spatiotemporal earthquake patterns. An alternative approach is based on theapplication of the Weibull distribution to the interevent times of an earthquake sequence asithas been performed by many authors (Hagiwara, 1974; Rikitake, 1976; Rikitake 1991).Hasumi et al. (2009) used the Weibull-log Weibull distribution for the study of the interoccurrence times of earthquakes in Japan.The latter distributions haverenewedtheir use in geosciences, since theycan be used in seismic hazard assessment (Votsi et al., 2011).It is the scope of the present work to use the Weibulldistribution for the analysis ofthe cumulative distributionof the interevent times along the seismic zones of the HSZ.

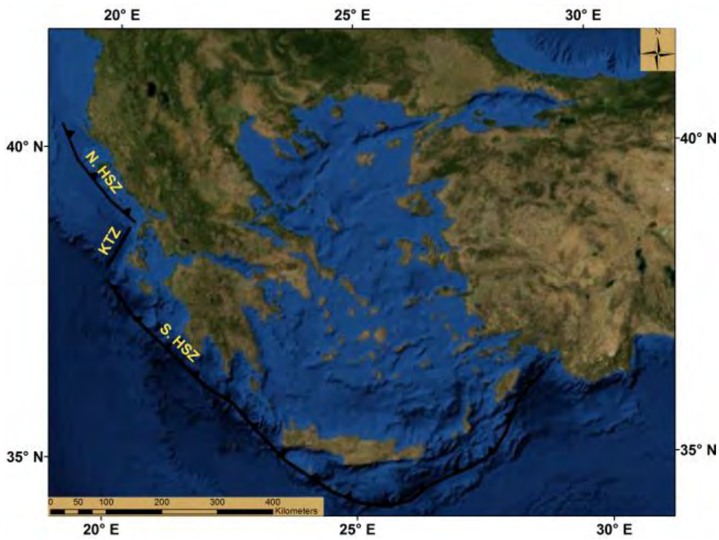

Figure 1 - The active trenches (thick dark lines with solid barbs) for the HSZ, as Royden and Papanikolaou (2011) indicate them. The Kephalonia Transform Zone (KTZ) separates the northern part (N. HSZ) of the Hellenic subduction boundary from the southern one (S. HSZ).

2. Seismic Zones and Earthquake Dataset

Papaioannou and Papazachos (2000) separated the region of the Aegean and the surrounding area in 67 seismogenic sources. This separation is based on previous work on seismic zonation, work on seismicity and active tectonics, as well as on geological and geomorphological information. In the present work, we use the external seismic sources, which are associated with the compressional stress field to define a dataset regarding the subduction zone. These sources have axes parallel to the external coast of the area, to the strikes of the seismic faults (thrust or strike- slip), and are associated with the lithospheric convergence (Papazachos, 1990).In order to create a dataset with a significant number of events that will lead us in a confidence result,we merge the external seismic sources to form larger areas of study called seismic zones, as it is proposed in Papadakis et al., (2013). It should be noticed that the latter process is in fully agreement with the zonation study originally proposed in Papaioannou and Papazachos (2000).Table 1 provides the composition of each seismic zone as regards the seismic sources forming them and the correspondent number of seismic events used in each of the zones.We note that the dataset used in this study is based on the updated and extended earthquake catalogue for Greece and the adjacent areas by Makropoulos et al. (2012). It concerns shallow earthquakes (focal depth ≤ 60km) and covers the period 1976-2009 (Figure 2).

Table 1 – The composition of the seismic zones used in this study and the correspondent number of seismic events.

Seismic Zones	Seismic Sources	Seismic Events
1	4,5	111
2	6,7,8,11	265
3	9,10,12,13	248
4	14,15,16,17	327
5	18,19,20	179

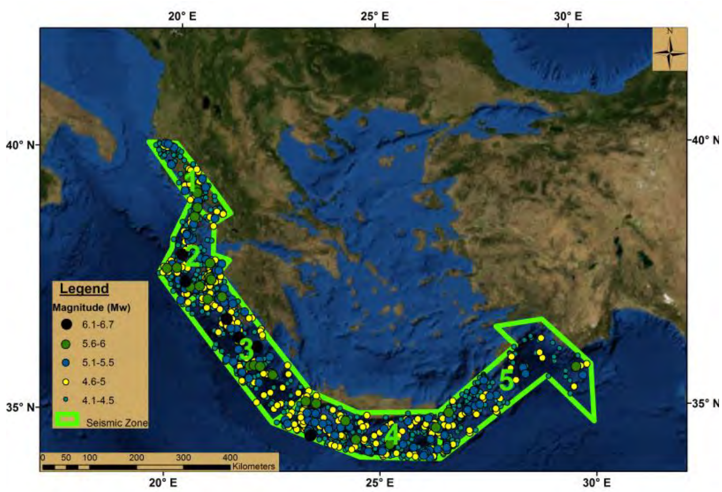

Figure 2 - The seismic zones (polygons 1-5) (Papaioannou and Papazachos, 2000) of the HSZ, and the seismic events (colored circles) (Makropoulos et al., 2012) of shallow earthquakes (focal depth ≤ 60km) covering the period 1976-2009.

Moreover, Makropoulos et al. (2012) have computed the magnitude of completeness (Mc) of their updated catalogue for the period 1976-2009 to be as Mc = 4.1.The final dataset used in this study, is extracted usingthe application of the window method, introduced by Gardner and Knopoff (1974) and modified by Uhrhammer (1986)for thedeclustering of the original earthquake catalogue.

3. The Weibull Distribution

The probability density function (pdf) for a Weibull distribution is given as:

Equation 1–The probability density function (pdf)

$$p(t) = \frac{\beta}{\tau}\left(\frac{t}{\tau}\right)^{\beta-1} exp\left[-\left(\frac{t}{\tau}\right)^{\beta}\right],$$

whereβ is the shape parameter or the Weibull modulus and τ is the scale parameter.

The cumulative distribution (cdf) of the Weibull distribution is given as:

Equation 2–The cumulative distribution function (cdf)

$$P(t) = 1 - exp\left[-\left(\frac{t}{\tau}\right)^{\beta}\right],$$

where P(t) is the fraction of the recurrence times that are shorter than t.

The survival function R(t) is given as:

Equation 3–The survival function

$$R(t) = 1 - P(t).$$

The hazard function h (t_0) is the pdfthat an event will occur at a time t_0 after the occurrence of the last event (Abaimov et al., 2008). The hazard function exhibits a power-law behavior and it is given as:

Equation 4–The hazard function

$$h(t_0) = \frac{pdf}{1 - cdf} = \frac{\beta}{\tau}\left(\frac{t_0}{\tau}\right)^{\beta-1}.$$

If β>1 the probability that an earthquake will occur increases as a power of the time t_0 since the last earthquake. For β=1 the Weibull distribution reduces to the exponential distribution. That means that earthquakes occur randomly.For β<1 the Weibull distribution is known as the stretched exponential distribution(Yakovlev et al., 2006).

4. Interevent Time Cumulative Distribution

The cumulative distribution of the interevent times for each seismic zone and for the HSZ as a unified system is given in Figure 3. The best fit of the Weibull distribution using the maximum likelihood estimation is also presented.

The calculated Weibull parameters are presented in Table 2. An inspection to the obtained values of the shape parameter β suggests its increase as we move from seismic zone 1 to seismic zone 5. The β value is equal to 0.92 for the HSZ as a unified system. It becomes equal to 0.77 in seismic zone 1. Moving southward it increases and becomes equal to 0.88 and 0.89 in seismic zones 2 and 3, respectively. This trend continues to appear along the northeast portion of the Hellenic arc presenting values equal to 0.95 and 1.08 in seismic zones 4 and 5 respectively. On the other hand the scale parameter τ shows variations that do not follow the trend of the shape parameter and has a value equal to 9.15*105(sec) for the HSZ as a unified system.

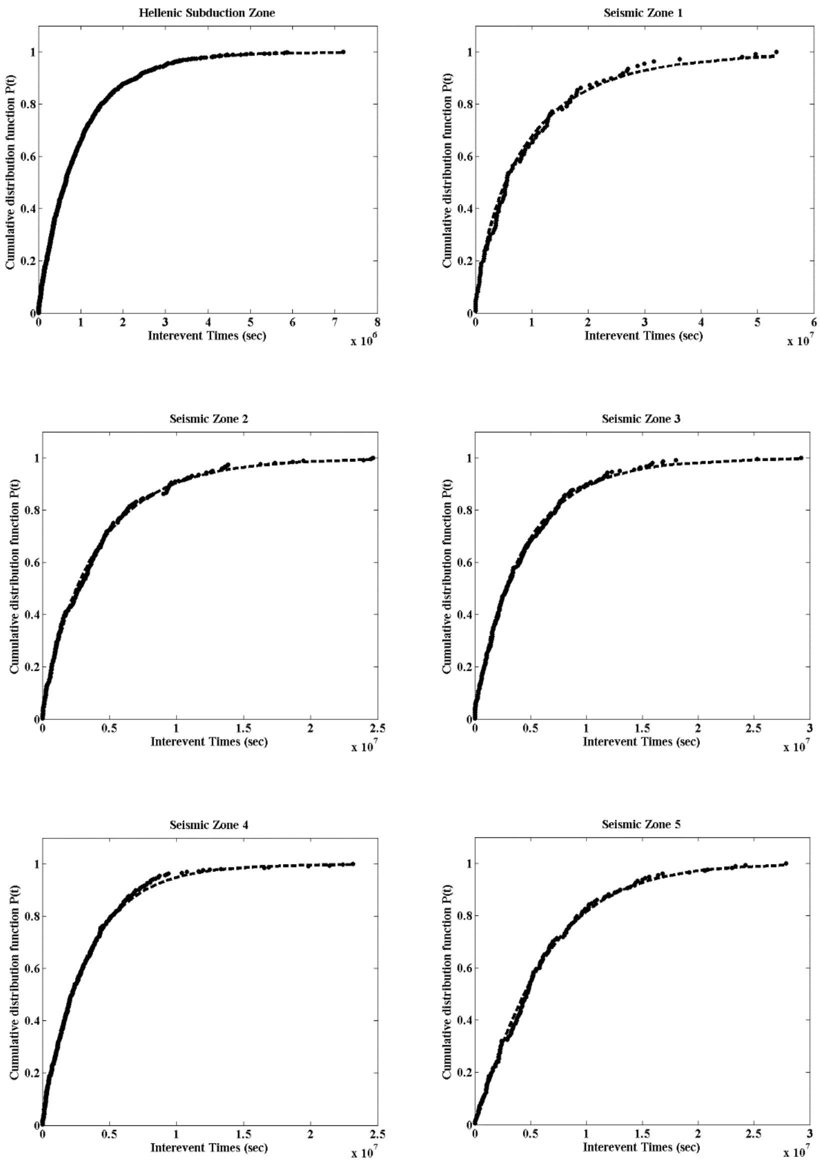

Figure 3 - The cumulative distribution ofinterevent times for each seismic zone and for the HSZ as a unified system. The black discontinuous line is the best-fit Weibull distribution. The estimation of the Weibull parameters has been performed using the maximum likelihood estimation.

Table 2 - The Weibull parameters β and τ and their 95% confidence intervals [β1, β2] and [τ1, τ2] for each seismic zone and for the HSZ as a unified system.

Seismic Zones	β	τ(sec)	[β1,β2]	[τ1, τ2]
HSZ	0.92	$9.15*10^5$	[0.88, 0.96]	[$8.56*10^5$, $9.77*10^5$]
1	0.77	$8.50*10^6$	[0.66, 0.90]	[$6.61*10^6$, $1.09*10^7$]
2	0.88	$3.81*10^6$	[0.80, 0.97]	[$3.30*10^6$, $4.40*10^6$]
3	0.89	$4.12*10^6$	[0.81, 0.99]	[$3.56*10^6$, $4.76*10^6$]
4	0.95	$3.17*10^6$	[0.87, 1.03]	[$2.81*10^6$, $3.57*10^6$]
5	1.08	$6.15*10^6$	[0.96, 1.22]	[$5.34*10^6$, $7.09*10^6$]

5. Conclusions

In the present work the analysis of the interevent timedistribution using the Weibull distribution is being investigated. The studied area is the Hellenic subduction belt divided in 5 seismic zones as it is recently used in Papadakis et al., (2013) and as it is originally proposed in Papaioannou and Papazachos (2000)for the separation of the Aegean and the surrounding area in 67 seismogenic sources. The declusteredearthquake dataset concerns earthquakes with Mc= 4.1 and covers the period 1976-2009.The Weibull distribution used in this study fits rather well to the observed distributionsimplying its usefulness in the investigation of the interevent time distribution along the HSZ.The shape parameter βpresents increasing values as we move from the northwestern (seismic zone 1) to the southeastern part (seismic zone 5) of the Hellenic subduction boundary. On the other hand the scale parameter τ presents variations that do not follow the trend of the shape parameter along the seismic zones of the HSZ.

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