Seismicity anomalies prior to the June 8th 2008, Mw = 6.4 earthquake in Western Greece

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Abstract

The epicentral area of the Mw=6.4, June 8th , 2008 main shock in northwestern Peloponesus, Western Greece, had been forecasted as a candidate for the occurrence of a strong earthquake by independent scientific investigations. This study concerns the seismicity of a large area surrounding the epicenter of the mainshock using the seismological data from the monthly bulletins of the Institute of Geodynamics of the National Observatory of Athens. This data set is the most detailed earthquake catalog available for anomalous seismicity pattern investigations in Greece. The results indicate a sudden seismicity rate a decrease seven years prior to the June 8th main shock and a two and a half year period of seismic quiescence surrounding the epicentral area. This quiescence anomaly was succeeded by a preparatory period of acceleration in the seismic activity and a power law behavior of the cumulative foreshock seismicity.

1 Introduction

On June 8th, 2008 at 12:25 GMT, a moment magnitude Mw = 6.4 earthquake occurred in northwestern Peloponesus, western Greece, between the cities of Patras and Andravida (Figure 1). The shock was felt in almost all of Greece causing 2 deaths, about a hundred injuries and affected roughly 10000 houses with small to severe damage.

The earthquake parameters of the main shock as determined by the Institute of Geodynamics of the National Observatory of Athens (NOA - IG), provided epicentral coordinates at 37.98° N and 21.51° E, a focal depth of 25 km and a moment tensor solution of a strike - slip focal mechanism with a northeast - southwest direction, as also observed from the aftershock distribution in figure 1 (http://bbnet.gein.noa.gr.MT.htm) , Ganas et., al., 2008).

During the first months of 2008, the seismicity rate in Greece increased when compared to that of previous years and the June 8th earthquake in the northwestern part of Peloponesus was preceded by a two strong main shocks that struck the eastern and southwestern parts of the wider region, as shown in figure 2. The earthquake series begun on January 6th near the city of Leonidion in eastern Peloponesus (37.10^0 N - 22.82^0 E) with a main shock of M=6.1 and continued on February 14th near the city of Methoni in southeastern Peloponesus, with two strong shocks of M=6.2 and M=6.1, that occurred within a few hours of each other at 36.41^0 N – 21.64^0 E and 36.22^0 N – 21.80^0 E, respectively.

Prior to the June 8th earthquake precursory, anomalous seismicity patterns and anomalous electric field variations, were respectively reported by Papadimitriou (2008) and also by Sarlis et. al., (2008). Both investigations forecasted a large earthquake to occur around the spring of 2008 and interestingly enough the forecasted location of the impending earthquake in both studies included the area of northwestern Peloponesus as a candidate area. In particular the study of Papadimitriou (2008) concerning the seismicity patterns around western Greece (37.0^0 – 39.5^0 N and 19.00^0 - 22.00^0 E almost a year prior to the June 8th main shock, indicated an elliptical region of anomalous decelerating – accelerating moment release (DAMR) seismicity pattern centered at 38.0^0 N – 20.5^0 E as the forecasted epicentral region and this region. This elliptical region is found to lie within the wider rectangular region : 37.50^0 - 38.60^0 N and 20.00^0 - 23.00^0 E that was indicated by the forecast of Sarlis et al. (2008) as the possible impending earthquake region by the method of "natural time analysis" (Varotsos et. al., 2005a) of the on going seismicity (Varotsos et. al., 2005b). Both of these studies used the preliminary catalog of NOA-IG with a threshold magnitude of M=3.9 for their respective investigations.

The spatial and temporal coincidence in the two forecasts, motivated this author to study the seismicity patterns of the wider region of interest with the preliminary (electronic) Greek earthquake catalog, from NOA – IG's web site (http://www.gein.noa.gr/services/cat.html). Using the methodology of Chouliaras and Stavrakakis (2001), an area exhibiting seismic quiescence was identified within the wider forecasted regions of the aforementioned studies. The area of 10 kilometers length and a few kilometers width and a NE - SW orientation, was located to the southwest of Patras and to the northeast of Andravida. This result was communicated by e-mail to P. Varotsos (pers. comm.., February 29th, 2008) and three months later, on June 8th , 2008, occurred the Mw = 6.4 main shock at the anomalous area which was indicated by the preliminary study of this author .

This investigation concerns the detailed analysis of the seismicity patterns for the wider region, 37.00^0 - 39.00^0 N and 20.00^0 - 23.50^0 E, surrounding the epicenter of the Mw = 6.4 mainshock, using the seismological data from the final monthly bulletins of the Institute of Geodynamics of the National Observatory of Athens (NOA – IG). The data set used is the most detailed earthquake catalog available for anomalous seismicity pattern investigations in Greece and it's exploitation for detecting precursory seismicity anomalies is discussed.

2 Data Analysis and Results

The Greek National seismological network is operated by NOA-IG since 1897 and it's first instrumental earthquake catalog was published in 1950. In 1964, the operation of a network of electromagnetic type sensors and analog registration begun and the practice of a systematic data analysis, bulletin production and routine archiving, common to international seismological observatories was initiated.

The monthly bulletins of NOA – IG from 1964 to 2000 have been used to compile an electronic earthquake catalog, the most detailed instrumental seismicity catalogue for Greece. The Internet catalogue of NOA - IG contains earthquake data from the monthly bulletins until the year 2000 and from then on the catalog is updated daily with the preliminary bulletins (http://www.gein.noa.gr/services/cat.html). The NOA – IG monthly bulletins for the period 2000 onwards are retrieved either from the ISC or the PDE catalogs.

For the purposes of this study we compile an earthquake catalog for all of Greece (geographic region 34^0 – $42\,^0$ N and 19^0 – 29 E^0) from the data of NOA - IG's monthly bulletins from 1964 until 2007 inclusive and for the year 2008 we use the data from the preliminary Internet catalog. This data set is used as input to the ZMAP software package (Wiemer et al., 1995) which is employed for all subsequent data analysis in this investigation. The seismic quiescence hypothesis of Wyss and Haberman (1988) applies to crustal earthquakes and this investigation mainly concerns earthquakes with depths less than 50 kilometers, in the rectangular sub region : 37.00^0 - 39.00^0 N and 20.00^0 - 23.50^0 E to directly compare with the results of the Papadimitriou (2008) and Sarlis et. al., (20008).

The time variation of the cumulative seismicity from the NOA – IG earthquake catalog from 1964 till 2008 is shown in figure 3. The four curves labeled a to d, respectively show the time variation of the cumulative: a) crustal seismicity for the entire Greek area, b) declustered crustal catalogue for the entire Greek area, c) crustal seismicity for the sub region, d) declustered crustal seismicity of the sub region.

The entire NOA – IG catalogue for Greece from 1964 till the June 8th, 2008 main shock, contains 69958 seismic events and a total of 68344 seismic events have depths less than 50 kilometers (curve *a,* figure 3). Significant network upgrades and installation of new seismic stations for the NOA – IG seismic network occurred in 1982, 1995, 2000 and 2004 and these periods show accelerated seismicity due to the improved detectability of the network and the rapid increase of registered earthquakes of small magnitudes. This power law behaviour of the evolving seismicity is also observed for the sub region in curve *c* of figure 3 that contains a total of 24432 crustal events.

On the other hand, sudden jumps in seismicity due to the occurrence of large earthquakes and their aftershock sequences (i.e., the Gulf of Corinth earthquake, February 1981, earthquakes in Kozani and Aigio during May-June 1995, Athens earthquake in September 1999) may be treated by the declustering algorithm of Reasenbeng (1985). The input parameters of the Reasenberg algorithm, Tau max (the maximum look ahead time for clustered events), Xmeff (the effective lower magnitude cut off for the catalogue) and the epicenter and depth errors, have been tested and tuned accordingly for the NOA -IG earthquake catalog, to values of 30 days, 2.0 Richter, and 10 kilometers, respectively. This procedure is shown to sufficiently remove aftershock clusters as shown by the smoothness of curves *b* and *c* in figure 3, nevertheless the power law behaviour of the curve due to NOA – IG's network expansion by the deployment of new seismological stations is persistant and should be seriously considered when investigating precursory accelerating moment release (AMR) models in the Greek earthquake catalog.

As mentioned earlier, two large earthquakes struck the eastern and southern coasts of Peloponesus, preceding the June 8^{th} event and a seismicity rate increase is observed in the Greek earthquake catalog during the first five months of 2008. In figure 4 the cumulative seismicity rate in all of Greece for the first 5 months of 2008 shows an increase of around 140%, when compared to the cumulative seismicity rate per year for the previous 10 years. To the contrary, figure 4b shows that the seismicity rate in the rectangular sub - region of investigation in this study has slightly decreased by 9% for the same period, thus justifying the closer investigation of seismic quiescence.

The denseness of network stations and the station sitting geometry of NOA – IG's seismic network is responsible for the detectability of seismic events and the spatial variation of Mc in Greece (http://www.gein.noa.gr/services/net_figure.gif). The spatial distribution of the magnitude of completeness (Mc) of the NOA – IG earthquake catalog for the rectangular sub region is shown in figure 5. Easily one may distinguish the red areas to the west towards the Eastern Ionian Sea with poor detectability compared to the dark blue area the east near Athens, of enhanced detectability. The goodness of the frequency magnitude distribution (FMD) fit to power law in figure 6, for the earthquake data of the sub region of interest in this study, suggests a cut – off magnitude of Mc = 3 as sufficient for this seismicity rate study in the wider epicentral area of the June 8th, 2008 main shock, in order to ensure homogeneity and completeness for the catalog data. The Genas procedure (Haberman, 1983) in Zmap also investigated for changes in reporting for the seismicity data of this sub region and no such artifact was shown to exist in the last decade of observations, however the installation of the EVR seismic station at 38.92^0 N– 21.81^0 E, improved the completeness of the catalog and the detectability of the network around 1998.

Since seismic quiescence has shown promising results in identifying precursory anomalies related to crustal main shocks (Wyss, 1997a, 1997b), we map the seismic quiescence in the sub region, as defined by Wyss and Habermann (1988) using the gridding method of Wiemer and Wyss (1994) and the ZMAP analysis software (Wiemer et al., 1995).

Using ZMAP we measure the significance of seismicity rate changes at the nodes of a 0.05^0 grid spacing, because this is related to the accuracy of epicentral determinations of the catalog and it also provides a dense coverage in space. At each node we took the nearest N earthquakes and searched for rate changes by a moving time window T_W, stepping forward through the time series by a sampling interval. The sampling interval is selected as a time step of one month in order to have a continuous and dense coverage in time and N and T_W values are usually selected accordingly in order to enhance the quiescence signal and this choice does not influence the results in any way.

Since we want to investigate the quiescence hypothesis which postulates that the quiet volume overlaps with the main shock source volume we wish to keep N constant in order to satisfy statistical assumptions for evaluation. For this reason a choice of N=70 events will sample volumes with radii ranging between 5 and 10 kilometers in the Greek catalog and these are reasonable dimensions for sampling seismogenetic volumes that generate large main shocks in Greece and whose dimensions have been investigated by Chouliaras and Stavrakakis (1997).

In order to rank the significance of quiescence, we used the standard deviate Z, generating the LTA(t) function (Wyss and Burford, 1985, 1987; Wiemer and Wyss, 1994)

$$Z=(R1-R2)/(S1/n1+S2/n2)^{1/2} \qquad (1)$$

which measures the significance of the difference between the mean seismicity rate within window R1, and the backround rate R2, defined as the mean rate outside the window but within the same volume. S1 and S2 are the variances of the means and n1 and n2 are the corresponding number of bins with a measured seismicity rate. Thus at each node a z value is computed and these z-values are then ordered according to size.

The computed z-values are then contoured and mapped, revealing the z-value distribution at the beginning of the window for which they are evaluated, since we want to define the onset of a significant rate change in the seismicity.

Since the length of the quiescence window is unknown for our study we varied the window length from 1.5 to 7 years to enhance the possible quiescence anomalies. Other studies have reported a range of T_{W} = 1.5 –7 yrs for seismic quiescence prior to crustal main shocks (Wyss 1997a,b) and also that the duration of quiescence as well as the rate of earthquake production, varies, depends on the size of the sampled volume for the Greek earthquake catalog (Chouliaras and Stavrakakis, 2001).

The z-value map for the rectangular sub region with a time window of Tw = 2.5 yrs starting at 2001.3, is presented in Figure 7a. Easily one observes the quiescence anomaly related to the epicenter of the June 8th main shock as well as more distant anomalies to the eastern part of the investigated region. In this section we will focus on the anomaly in the northwestern part of Peloponesus and comments will be made in the discussion section of this manuscript regarding the other anomalies.

The elongated lobe shaped quiescence anomaly with a Z value around 6 in figure 7a, includes the epicenter of the main shock and a large part of it's aftershock area when one compares this result with figure 1. The anomaly extends to the northeast of the epicenter almost parallel to the aftershock distribution and the nearby coastline and vanishes to the northwest of the epicenter. Around the quiescence anomaly the seismicity increases and the pattern resembles a Mogi 'doughnut' seismicity anomaly (Mogi, 1985). In figure 7b the cumulative seismicity of two volumes within the quiescence anomaly of figure 7a are plotted as a function of time. The top curve (red) is centered at 38.03^{0} N and 21.44^{0} E lying just to the northwest of the main shock and the bottom curve (blue) is centered at 38.03^{0} N and 21.55^{0} lying just to the northeast. Comparing the two curves one notices differences in the earthquake production of the two sampled volumes having respective radii of 8.3 and 7.7 kilometers approximately, in order to produce N=70 events. In both curves the quiescence anomaly is clearly observed to begin around 2001.3 and has a duration of approximately 2.5 years.

Following the period of quiescence around 2004, both curves show a period of accelerated seismicity and a power law behaviour prior to the main shock. The period of accelerated seismicity after the quiescence period may be analysed with the power-law time-to-failure relation in Zmap (Weimer, 2001). This relation is of the form

$$\sum \Omega (t) = K+(k/(n-1)) \cdot (t_f - t)^{m} \qquad (2)$$

where $\sum \Omega (t)$ is the cumulative energy release and Ω is determined from the earthquake magnitude M using the expression

$$\log_{10} \Omega = c \cdot M + d \qquad (3)$$

where c, K, k and n are constants, m=1-n ($n \neq 1$) and t_f is the time-to-failure Bufe et. al., 1994, Bufe and Varnes, 1996, Varnes, 1989).

Figure 8a shows the power law fit to the cumulative seismicity curve of the blue curve of figure 7b five years before the mainshock and figure 8b for the time period a few months prior to the main shock. In both cases the power law of the time to failure model is fitting closely both, the long term and the short term foreshock activity.

For comparison purposes we show the z value map for the declustered catalog near the epicentral region in figure 9a, using the same time window as in the clustered case of figure 7a. Easily one observes the quiescence anomaly to also persist in the declustered catalogue, in the same area and of the same geometrical distribution as in the clustered data. Figure 9b confirms the existence of the quiescence anomaly in the cumulative curve of the volume centered just to the north east of the main shock, at the same location as the blue curve of figure 7b, however only 50 events are produced from the same volume because of the declustering procedure. Again one notices evident similarities in the two cases, the presence of a quiescent period followed by a period of accelerated seismicity prior to the occurrence of the main shock.

3 Discussion and Conclusions

The June 8th , 2008 earthquake in north - western Peloponesus in Greece, came after a period of increased seismic activity that included the occurrence of two strong earthquakes in the perimeter of eastern and southwestern Peloponesus in the previous five months. Prior to this event, two independent scientific investigations had forecasted the occurrence of a strong earthquake in a wider region which included the actual epicenter and at an anticipated time window that included the main shock (Papadimitriou, 2008, Sarlis et. al., 2008). In addition to these, a preliminary investigation by this author, three month's before the main shock, narrowed down an elliptical area just a few kilometers to the southeast of the actual epicenter that exhibited seismic quiescence (P. Varotsos, pers. comm.., 2008).

For the detailed investigation of the seismicity prior to the June 8th, 2008 main shock that the earthquake catalog of Greece from 1964 till 2008 is compiled from the final monthly bulletins of NOA – IG. A total of 69958 events comprise the entire catalogue up to the June 8th main shock and 64344 of these earthquakes have depths less than 50 kilometers and are considered in this investigation. The catalog data prior to the June 8th main shock, indicate that the seismicity rate in all of Greece for the first five months of 2008 showed an increase by 140% compared to the rate of the previous ten years, however the seismicity rate in the wider region containing the epicenter of the main shock showed a 9% decrease for the same time periods.

A detailed analysis concerning the homogeneity and completeness of the catalog for the wider epicentral region indicates a magnitude of completeness of M>3 as a lower magnitude threshold in order to closer investigate the seismic quiescence hypothesis prior to the June 8th main shock (Wyss and Habermann, 1988). The methodology of mapping seismic quiescence for crustal earthquakes in Greece (Chouliaras and Stavrakakis, 2001) is applied to the earthquake catalogue of NOA – IG for the wider epicentral region of the June 8th main shock that includes the investigated regions by Papadimitriou (2008) and Varotsos et. al. (2008). The result indicates an area of seismic quiescence surrounding the epicentral and aftershock area of the main shock and this anomaly is persistent regardless of the mapping and declustering procedure. This quiescence begins almost seven years prior to the main shock around 2001.3 and lasts for roughly 2.5 years. The geometrical distribution of the quiescence found to surround the epicenter of the main shock resembles a Mogi doughnut pattern with three quiescence lobes covering most of the afteshock area.

Following the period of quiescence a period of activation exists and a power law time-to-failure model seems to describe the evolution of the seismicity until the occurrence of the main shock. The duration of this activation period in this case is of the order of 4.5 years approximately twice as long as the quiescence period and there exists a second sub period just a few months prior to the earthquake in which the time-to-failure model is found to approximate the local foreshock activity.

Both of these phenomena have been also observed in the seismicity pattern investigation of Papadimitriou (2008) concerning this region. In that investigation the preliminary catalog of NOA-IG was used and the threshold magnitude of the investigation was M>3.9 with a volume of 90 kilometer radius centered around the region of the main shock with a data set of only 776 events from 1999 till 2007.1. On the other hand the investigation of Sarlis et. al. (2008) considered also preliminary data from NOA-IG to investigate the evolution of the seismicity in the 'natural time' concept, that is the seismicity that evolves in a wider region surrounding the epicenter, beginning at the time of occurrence of an electrical precursor signal. Prior to the June 8^{th} main shock this particular seismicity study considered also events with M>3.9 from the preliminary NOA-IG earthquake catalog for a wide rectangular region around the epicenter since the appearance of a precursory electric signal on February 9, 2008. The on-going seismicity until the main shock studied a total of 20 events with M>3.9 and reached the criticality stage of the employed model on May 27^{th} , just a few days prior to the main shock.

Evidently the data, results and methodology in this study are able to map with a greater accuracy the precursory seismicity patterns associated with the June 8^{th}, 2008 main shock around the wider epicentral and aftershock region. It appears that sudden rate changes such as quiescence are easier to map in the Greek earthquake catalog rather than accelerated seismicity phenomena with a catalog that is inherently contaminated with power law seismicity behaviour because of increased reporting of earthquakes due to network upgrades and expansions. This artificiality in the Greek catalog data may lead to erroneous interpretations regarding accelerating seismicity patterns and accelerated moment release (AMR) studies as discussed recently by Hardenbeck et. al. (2008).

At the time of preparation of this manuscript a strong seismic event with Ms=5.7 occurred on December 13th, 2008 at 08:27 UTC with epicentral 38.72^0 N and 22.57^0 E. A preliminary investigation may relate this seismic event to the prominent zmap quiescence anomaly on the northeastern part of the region mapped in figure 5a.

Recently Uyeda and Kamogawa (2008) reported on the success of associating precursory anomalies in the earths electric field to Greek earthquakes and the 'natural time' analysis of the on going seismicity as a new tool in evaluating the occurrence of the impending main shock (Varotsos et. al, 2008). After that report, the coincidence in the reporting of the successful forecast concerning the June 8th, 2008 earthquake by independent investigators that employed different methodologies, may encourage further cooperative multidisciplinary investigations for earthquake prediction research in Greece.

Figure Captions

Figure 1a. Map of the Mw=6.4 earthquake in Western Greece on June 8^{th}, 2008 and it's aftershock distribution. (after Ganas et. al., 2008).

Figure 1b. Map of the earthquake main shocks that struck Peloponesus in 2008.

Figure 2. The time variation of the cumulative seismicity from the NOA – IG earthquake catalog from 1964 till 2008. The four curves labeled a to d, respectively show the time variation of the cumulative: a) crustal seismicity for the entire Greek area, b) declustered crustal catalogue for the entire Greek area, c) crustal seismicity for the sub region, d) declustered crustal seismicity of the sub region.

Figure 3a. The cumulative seismicity rate per year in all of Greece.

Figure 3b. The cumulative seismicity rate per year in the of the region of investigation in this study.

Figure 4a. The spatial distribution of the magnitude of completeness of the area of investigation in this study.

Figure 4b. The frequency magnitude distribution (FMD) fit to power law of the area of investigation in this study.

Figure 5a. The z-value map for the rectangular sub region based on the NOA – IG bulletin catalog. The LTA cut is at 2001.3, the chosen window length is Tw = 2.5 years, N=70 events and a grid spacing of 0.05^0 are the inputs for the mapping procedure.

Figure 5b. The cumulative seismicity of two volumes within the quiescence anomaly as a function of time. The top curve (red) is centered at 38.03^0 N and 21.44^0 E lying just to the northwest of the main shock and the bottom curve (blue) is centered at 38.03^0 N and 21.55^0 lying just to the northeast.

Figure 5b. Zvalue map for the declustered catalog of the region of investigation.

Figure 6a. Power law fit to the time-to-failure equation for the cumulative seismicity, 5 years prior to the June 8^{th}, 2008 main shock.

Figure 6b. Power law fit to the time-to-failure equation for the cumulative seismicity, 5 months prior to the June 8^{th}, 2008 main shock.

Figure 7a. The z-value map for the rectangular sub region based on the NOA – IG de clustered catalog. The LTA cut is at 2001.3, the chosen window length is Tw = 2.5 years, N=50 events and a grid spacing of 0.05^0 are the inputs for the mapping procedure.

Figure 7b. The existence of the quiescence anomaly in the cumulative curve of the volume centered just to the north east of the main shock, (at the same location as the blue curve of figure 7a).

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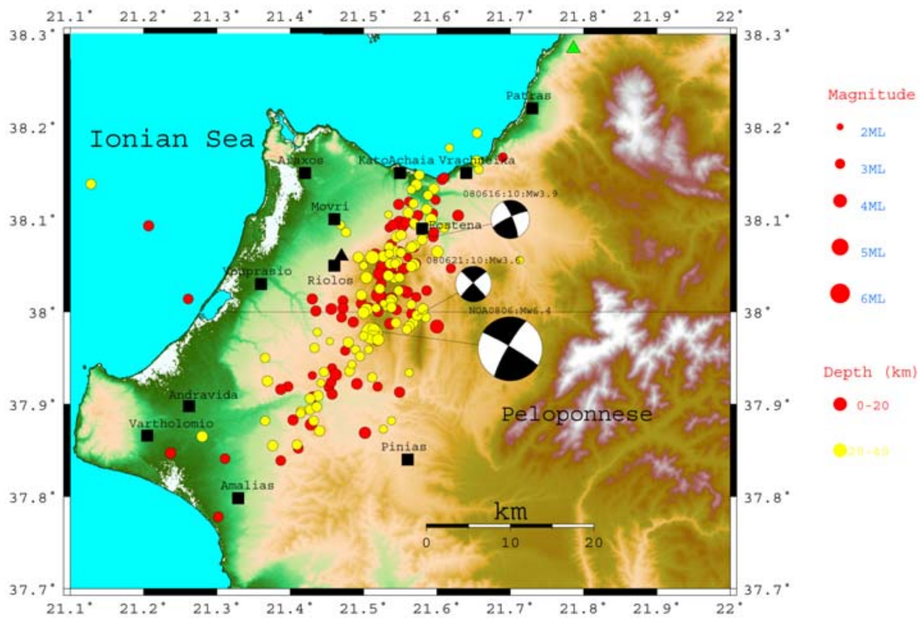
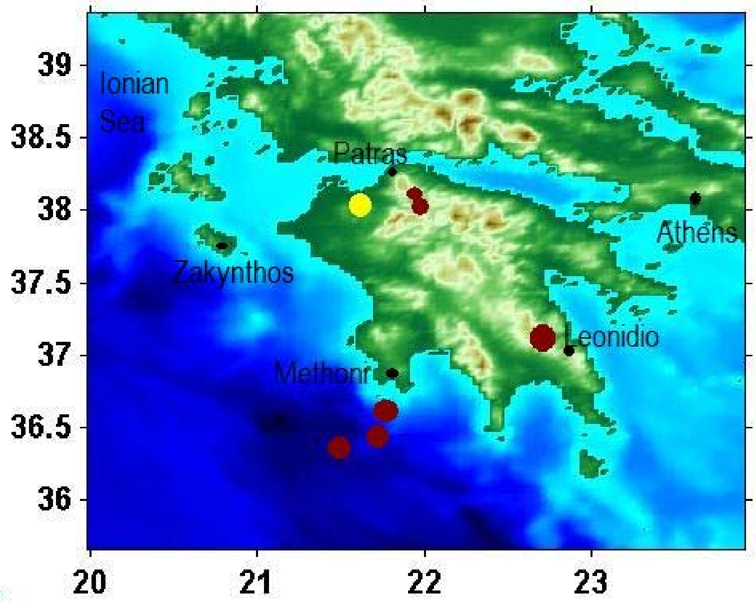


21.1° 21.2° 21.3° 21.4° 21.5° 21.6° 21.7° 21.8° 21.9° 22°
38.3° 38.2° 38.1° 38° 37.9° 37.8° 37.7°
Ionian Sea
Patras
KatoAchaia
Movri
Riolos
080616:10:Mw3.9
080621:10:Mw3.6
NOA0806:Mw6.4
Andravida
Vartholomio
Amalias
Pinias
Peloponnese
km
0 10 20
Magnitude
2ML
3ML
4ML
5ML
6ML
Depth (km)
0-20
20-40

Figure 1a.



39
38.5
38
37.5
37
36.5
36
20
21
22
23
Ionian
Sea
Patras
Athens
Zakynthos
Leonidio
Methonr

Figure 1b.

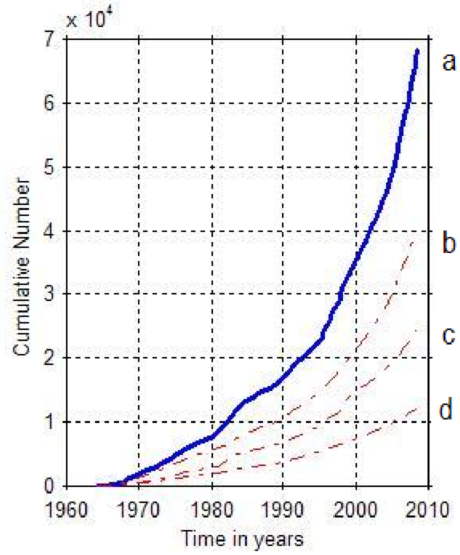

x 10^4
7
6
5
4
3
2
1
0
Cumulative Number
1960
1970
1980
1990
2000
2010
Time in years
a
b
c
d

Figure 2.

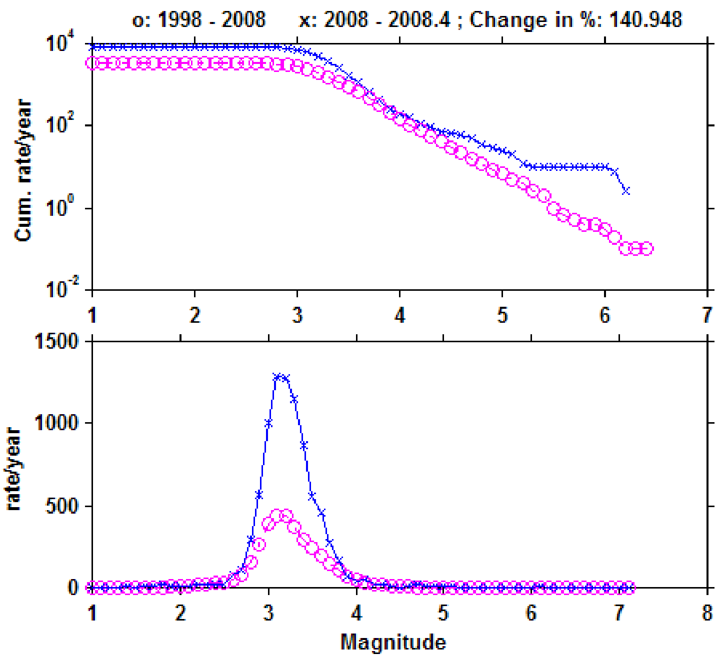
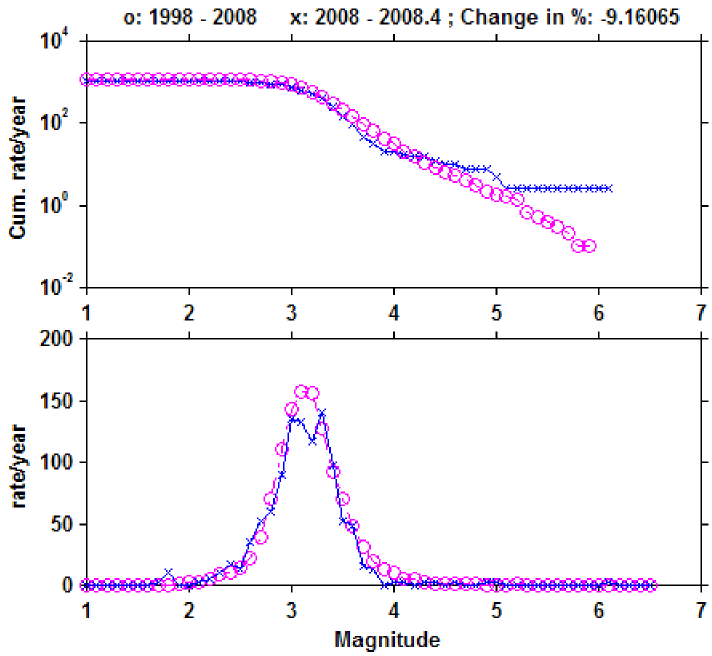
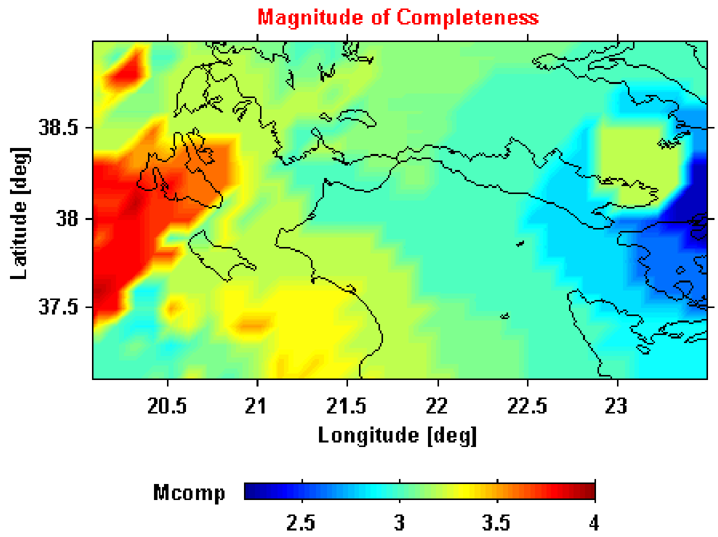

o: 1998 - 2008
x: 2008 - 2008.4 ; Change in %: 140.948
Cum. rate/year
rate/year
Magnitude

Figure 3a.



o: 1998 - 2008
x: 2008 - 2008.4 ; Change in %: -9.16065
Cum. rate/year
10^4
10^2
10^0
10^{-2}
1
2
3
4
5
6
7
rate/year
200
150
100
50
0
Magnitude

Figure 3b.



Magnitude of Completeness
38.5
38
37.5
Latitude [deg]
20.5
21
21.5
22
22.5
23
Longitude [deg]
Mcomp
2.5
3
3.5
4

Figure 4a.

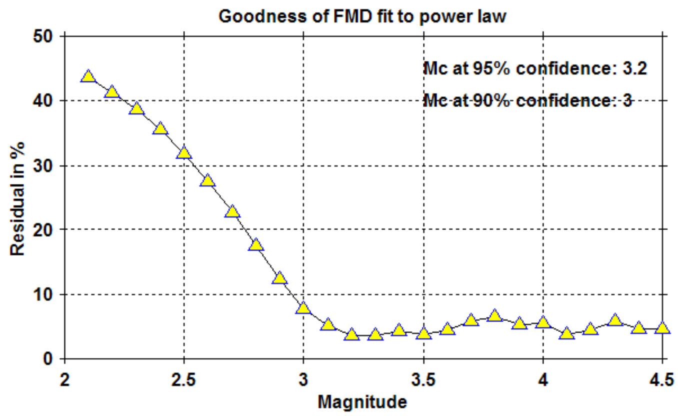

Goodness of FMD fit to power law
Mc at 95% confidence: 3.2
Mc at 90% confidence: 3
Residual in %
50
40
30
20
10
0
2
2.5
3
3.5
4
4.5
Magnitude

Figure 4b.

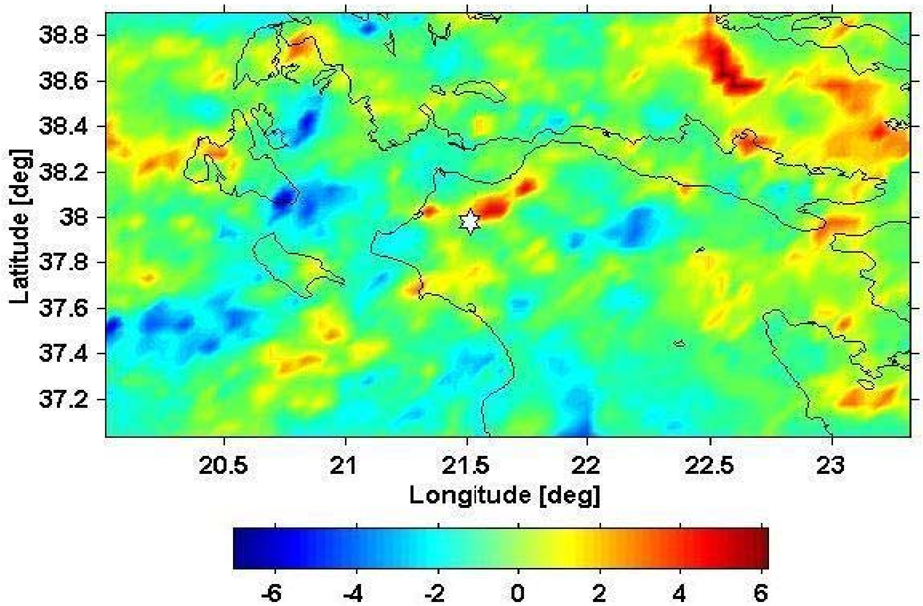
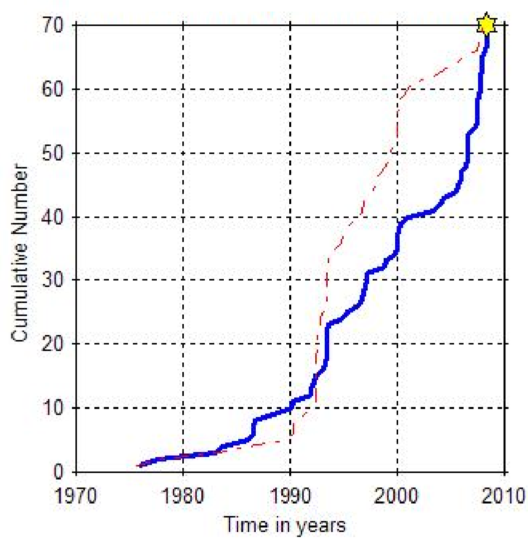
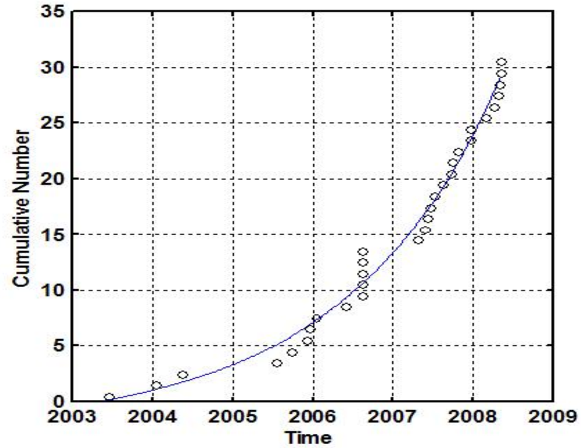

38.8
38.6
38.4
38.2
38
37.8
37.6
37.4
37.2
Latitude [deg]
20.5
21
21.5
22
22.5
23
Longitude [deg]
-6
-4
-2
0
2
4
6

Figure 5a.



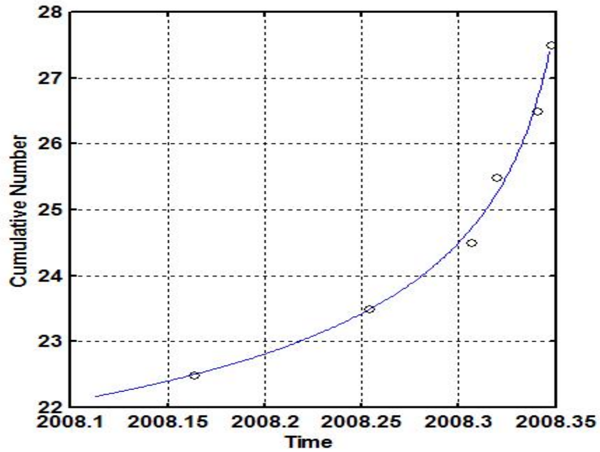
70
60
50
40
30
20
10
0
Cumulative Number
1970
1980
1990
2000
2010
Time in years

Figure 5b.



35
30
25
20
15
10
5
0
Cumulative Number
2003
2004
2005
2006
2007
2008
2009
Time

Figure 6a.



28
27
26
25
24
23
22
Cumulative Number
2008.1
2008.15
2008.2
2008.25
2008.3
2008.35
Time

Figure 6b.

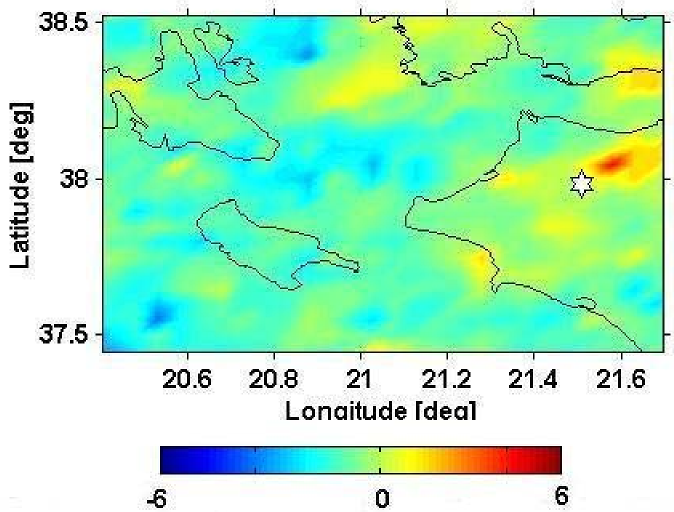
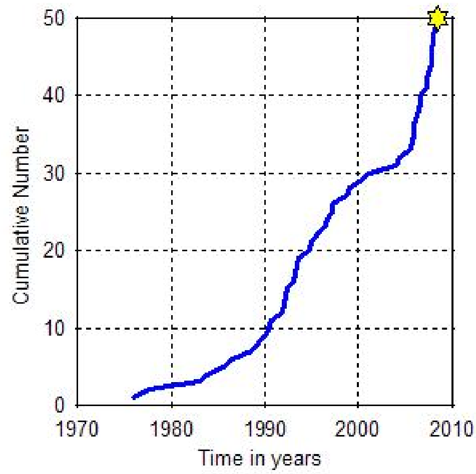

38.5
38
37.5
Latitude [deg]
20.6
20.8
21
21.2
21.4
21.6
Longitude [deg]
-6
0
6

Figure 7a.



50
40
30
20
10
0
Cumulative Number
1970
1980
1990
2000
2010
Time in years

Figure 7b.