An updated earthquake catalogue for Greece and adjacent areas since 1800

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ABSTRACT

An updated earthquake catalogue for Greece and adjacent areas is presented, which is the most recent version of several published catalogues and individual efforts, covering the period 1800-2007. The Makropoulos and Burton (1981) and Makropoulos, Drakopoulos & Latoussakis (1989) catalogues, covering the time span 1900-1985 were updated for the period 1986-2007, using instrumental parameters from the bulletin of the ISC, apart from magnitude. For Ms, the same procedure as before was applied, i.e. using the ISC body wave magnitude (m_b) and a regression equation. In the present update, Mw is also included for the whole period 1900-2007, calculated from the Scordilis (2006) formula. Maximum intensity, when available, was also inserted in the catalogue, with reference to its source and scale used, taking into account that in the 20th century at least three different macroseismic scales have been published. The catalogue was also extended backwards in time, including the 19th century historical earthquakes and recently developped techniques were applied, when the data allowed, for determining their parameters. A completeness test was finally applied to the instrumental part of the updated catalogue. Events with Ms≥4 are complete during the last 31 years of the catalogue (1976-2007) and those with half a magnitude unit larger for the last 57 years. The analysis also shows that the present catalogue contains almost all the events with magnitude equal to or greater than 5.0 and 5.5 after 1940 and 1911, respectively. Finally, no earthquake with Ms≥6 seems to have been omitted in the whole instrumental period.

Introduction

Greece lays in the middle of the collision between two tectonic plates, the Eurasian and the African, the latter sinking under the former at a rate that exceeds 3-4 cm/yr south and east of Crete. Greece, apart from the collision front, and due to its relatively small size, is broken into pieces, thus forming many seismic zones. It has the greatest seismicity in the whole of Europe. Half the energy of all the earthquakes occurring in Europe is released in Greece. There is no Greek province that doesn't host seismic sources throughout the last centuries. Fortunately, approximately 75% of Greek earthquakes are either offshore, away from inhabited areas, or at several km of depth, and therefore are not highly disastrous. Modern demands on seismology have produced a requirement for an earthquake catalogue which is as accurate, homogeneous and as complete as possible so that tectonic features may be delineated and assessed in order to be used for seismic risk or zonation and land use regulation and planning.

Previous Efforts

A number of Greek earthquake catalogues existed since 1879 (Schmidt 1879; Galanopoulos 1953; Annales de l'Observatoire National d'Athènes 1893-1936 and NOA monthly and annual bulletins since 1949). The first most systematic attempt to accumulate and classify all earthquakes over a certain magnitude (~5) was made by Galanopoulos (GAL, 1960) for the period 1700-1960. Kárnik (1969) made an effort to present an earthquake catalogue of Europe with magnitude determinations and incorporated magnitude estimates. In 1970 the UNDP/UNESCO Survey of the Seismicity of the Balkan Region began giving first priority to the compilation of an earthquake catalogue (Shebalin et al., 1974) which covers the period up to 1970. The first attempt to relocate epicenters computed by the ISS for the Marmara region in NW Turkey, which is included in our area of investigation, was made by Crampin and Ucer (1975). Alsan et al. (ATB, 1975) published the first computerized earthquake catalogue for Turkey and adjacent areas. The Galanopoulos (1977) catalogue of Greek earthquakes with magnitudes greater than 5.5 since 1902 is a compilation of previous studies. Papazachos B. and C. (1989, 1997, 2003), as well as joint european efforts (BEECD, NERIES, SHARE) have presented historical earthquake catalogues.

Present Instrumental Catalogue - Previous Versions

The first earthquake catalogue for Greece for the period 1901-1978 with recalculated source parameters including magnitudes according to a consistent scheme was published by Makropoulos (1978) and further elaborated by Makropoulos & Burton (1981). The next elaboration of the catalogue for 1901-1985 was by Makropoulos et al. (1989).

1. DATA SOURCES

1.1 HYPOCENTERS

First phase arrival readings were extracted from the following sources:

1. 1913-1917: monthly bulletins of the British Association for the Advancement of Science
2. 1918-1963: bulletins of the Intern. Seismological Summary (ISS)
3. 1964-1985: bulletins of the Intern. Seismological Center (ISC)

1.2 MAGNITUDE

To determine Ms the real ground amplitudes reported by the following sources were used:

1. 1908-1959: annual bulletins of the Seismological Institute at Uppsala (SIU) for readings of Uppsala (UPP)
2. 1951-1955: annual bulletins of SIU for readings of Kiruna (KIR)
3. 1956-1963: monthly bulletins of SIU for all the Swedish network
4. 1901-1970: the UNESCO (UNS) catalogue (Shebalin et al., 1974)
5. 1964-1985: the ISC m_b magnitude determination

2. EARTHQUAKE RELOCATION

- All earthquakes with available first phase arrival readings were relocated using the Joint Epicenter Determination (JED) method (Douglas, 1967) and Herrin's '68' travel-time tables (Herrin et al., 1968).
- For the period 1917-1963, 605 events were relocated, while the parameters (except for magnitude) of the remaining events were adopted from the UNS, Papazachos and Comninakis 1982 (PC), UPP, GAL, ATB and ISC catalogues.

3. MAGNITUDE DETERMINATION

- The Magnitude Ms was taken as the average of UPP Ms (derived from long-period Benioff instruments) and KIR Ms (derived from Galitzin instruments), calculated using the formula:

$$Ms = \log(A/T) + 1.66 \log\Delta° + 3.3$$

- For a consistent Ms calculation over the period 1908-1968 the ATB regression equations between simultaneous recordings of the same earthquake from different instruments were used.
- Ms was calculated for the years 1964-1985 from the equation:

$$Ms = 1.37\ m_b(ISC) - 1.74$$

Present Catalogue-Current Version

The current version of the instrumental earthquake catalogue for Greece and adjacent areas has been updated for the whole period 1900-2007. The area of investigation is delineated, as in the previous versions, within latitudes 33°N-42.5°N and longitudes 19°E to 29°E north of the 38°N parallel and up to 30°E south of it, in order to also cover the Dodecanese Islands, with surface magnitudes Ms≥4.

Concerning the period 1986-2007, hypocenters were adopted from the bulletins of the ISC. The surface wave magnitude Ms is calculated again using the body wave magnitude determined by the ISC from the equation:

$$Ms = 1.37\ m_b(ISC) - 1.74$$

Furthermore, in the updated catalogue, moment magnitude Mw was calculated for all the events since 1900, using the following formulas (**Figure 1**):

Mw=0.67Ms+2.07 for 3.0≤Ms≤6.1 (Scordilis, 2006)

Mw=0.99Ms+0.08 for 6.2≤Ms≤8.2 (Scordilis, 2006)

Finally, macroseismic maximum intensity was also incorporated for the whole instrumental period, with its corresponding source.

The present version of the catalogue contains 6494 events (**Figure 2**), whereas the previous version (Makropoulos et al., 1989) included 4310 events. It is obvious that earthquake sources are spread all over Greece, with the exception of a few islands in Cyclades and Thrace.

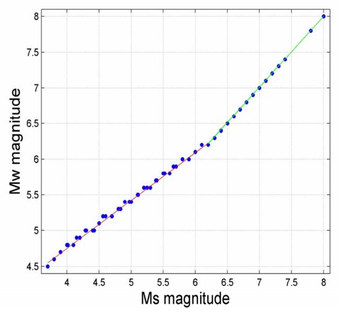

Figure 1

The majority of shallow earthquakes are located within a belt parallel to the Hellenic Arc, which extends north into Albania and south-east to the west coast of Turkey. Intermediate earthquakes are mainly constrained within the back-arc region. Significant earthquake clusters are observed in the Gulf of Corinth, as well as along the westward propagation of the north Anatolian Fault into the Aegean. The aftershock sequences of the Thessaloniki (1978), Volos (1980), Kozani-Grevena (1995) and Athens (1999) earthquakes are also evident. A sample of this catalogue containing events with Mw≥7 is displayed in **Table 1**.

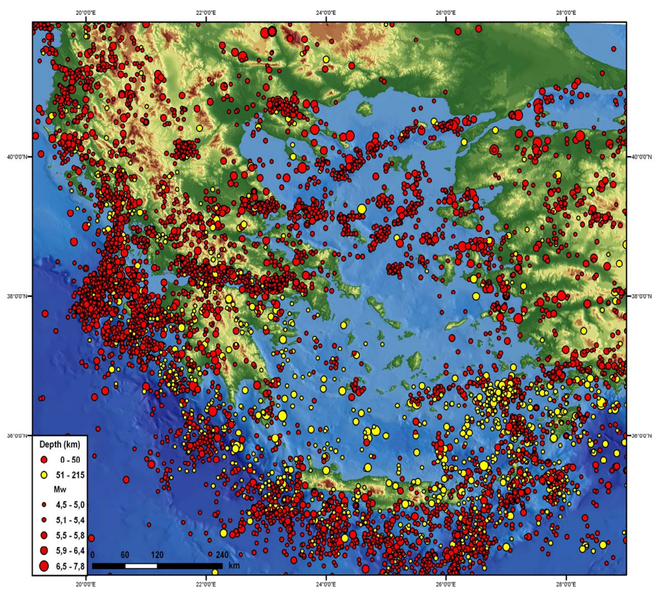

Figure 2

Yr	Mo	Da	Hr	Min	Sec	Lat°N	Lon°E	Dep	Inst	Ms	Mw	Imax	Sou
1903	8	11	4	32	54.0	36,30	23,00	120	UNS	8,0	8,0	7	SHA
1904	4	4	10	2	34.0	41,78	22,98	15	UNS	7,1	7,1	7	SHA
1904	4	4	10	25	55.0	41,80	23,10	18	UNS	7,8	7,8	7	SHA
1905	11	8	22	6	00.0	40,30	24,40	17	UNS	7,4	7,4	10	PAP
1912	8	9	1	29	00.0	40,60	27,20	16	UNS	7,3	7,3	10	PAP
1919	11	18	21	54	57.0	39,41	26,09	20	27	7,0	7,0	8	SHA
1926	3	18	14	6	14.0	35,99	30,13	42	81	7,0	7,0	8	PAP
1926	6	26	19	46	42.1	36,75	26,98	109	96	7,3	7,3	11	PAP
1926	8	30	11	38	04.5	36,76	23,16	26	75	7,0	7,0	8	PAP
1928	3	31	0	29	47.7	38,01	27,92	12	68	7,0	7,0	9	SHA
1928	4	14	8	59	58.0	42,34	26,02	19	88	7,0	7,0	9	SHA
1928	4	18	19	22	51.2	42,27	25,35	7	95	7,1	7,1	8	SHA
1932	9	26	19	20	43.0	40,39	23,81	5	134	7,1	7,1	9-10	SHA
1935	2	25	2	51	30.5	36,07	24,83	67	108	7,1	7,1	8	PAP
1939	9	22	0	36	34.2	38,78	26,73	5	81	7,0	7,0	8	PAP
1944	10	6	2	34	48.5	39,46	26,43	26	76	7,0	7,0	8	PAP
1948	2	9	12	58	17.9	35,32	27,15	25	124	7,2	7,2	9	SHA
1949	7	23	15	3	35.2	38,71	26,27	17	124	7,0	7,0	9	SHA
1953	3	18	19	6	16.8	40,20	27,52	8	259	7,4	7,4	8	NOA
1953	8	12	9	23	55.4	38,13	20,74	11	257	7,3	7,3	6-7	NOA
1955	7	16	7	7	17.2	37,68	27,20	31	232	7,0	7,0	8	NOA
1956	7	9	3	11	43.7	36,64	25,91	15	270	7,4	7,4	9	NOA
1956	7	9	3	24	16.5	36,45	25,51	95	57	7,2	7,2		
1957	4	25	2	25	45.6	36,48	28,58	66	274	7,1	7,1	8	NOA
1964	10	6	14	31	23.0	40,30	28,23	34	210	7,0	7,0	6-7	NOA
1968	2	19	22	45	42.4	39,40	24,94	7	333	7,2	7,2	9	NOA
1981	12	19	14	10	51.1	39,22	25,25	16	489	7,2	7,2	8	NOA
1983	1	17	12	41	30.1	38,07	20,25	17	565	7,0	7,0	6	NOA
1983	8	6	15	43	51.9	40,14	24,74	21	546	7,0	7,0	6	NOA

Table 1: The parameters listed for each earthquake are: year, month, day, hour, minute, second, latitude, longitude, focal depth, number of reporting stations or institute, surface-wave magnitude, moment magnitude, maximum observed intensity and source of macroseismic information.

Completeness

In order to assess the degree of completeness, that is to find the magnitude above which the catalogue can be considered as reasonably complete, or alternatively to assign time intervals in which a certain magnitude range is likely to be completely reported, the method introduced by Stepp (1971) and used in the previous versions of the catalogue was applied. **Table 2** summarizes the results of the application of the test of completeness on the catalogue. It can be seen that events with magnitude above 4 are completely reported for the last 31 years of the catalogue (1976-2007). No earthquake with magnitude 6 or greater seems to have been omitted for the whole period (i.e. 1900-2007).

Magnitude	Time required for stable recurrence rate (yr)	Period of completely reported events
Ms ≥ 4.0	5	1976-2007
Ms ≥ 4.5	20	1950-2007
Ms ≥ 5.0	25	1940-2007
Ms ≥ 5.5	45	1911-2007
Ms ≥ 6.0	60	1900-2007

Table 2

Historical period 1800-1900

Damaging earthquakes (Imax ≥ 7) were identified for this period from the existing databases, catalogues and seismological studies (e.g. NERIES database 2010, Taxeidis 2003, etc.). The parameters of these events, a sample of which is presented in **Table 3**, are strictly based on macroseismic intensities and their distribution. Concerning the epicenter:

- for events with one intensity datapoint the epicenter is given the coordinates of the corresponding locality
- for events with more than one intensity datapoints the epicenter is calculated according to their distribution

Such procedures were recently developed within NERIES project and are further elaborated in the framework of SHARE project, for the compilation of the European catalogue of historical earthquakes, based on related previous efforts. Similarly, the equivalent Mw is calculated using both the macroseismic intensities distribution and the attenuation of intensities with distance. In total, 140 events were listed with Mw≥4.5, which are mainly damaging or destructive.

It is noted that in many cases the epicenters and magnitudes of the historical earthquakes are characterized by the problem of uncertainty, obviously due to the nature of the intensity itself. Their epicentral distribution (**Figure 3**) seems to follow the pattern described for the instrumental period, a fact meaning that many of the significant events of the 19th century have been repeated in the 20th century.

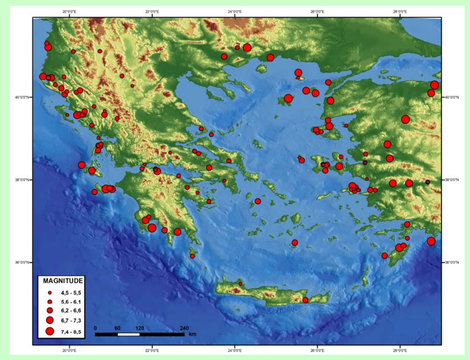

Figure 3

Yr	Mo	Da	Ix	Sc	Ax	Lat	Lon	UnC km	Mw	UnM	Source
1867	2	4	10	MM	Lixouri	38,359	20,297	± 8.5	7,3	± 0.0	Thess. Macro DB, 2010 (13 MDPs)
1867	3	7	10	EMS	Kloumidados	39,297	26,286	± 5.8	6,9	± 0.20	Taxeidis, 2003 (108 MDPs)
1867	3	29	8	MM	Drama	41,207	24,059	± 2.2	5,9	± 0.20	Thess. Macro DB, 2010 (3 MDPs)
1867	9	20	9	MM	Maroulia	36,740	22,616	± 7.4	6,8	± 0.30	Thess. Macro DB, 2010 (6 MDPs)
1868	5	15	8	EMS	Pagondas	37,717	26,900		5,9		Taxeidis, 2003 (4 MDPs)
1868	10	3	8	MM	Skiathos	39,093	23,432	± 3.2	6,1	± 0.10	Thess. Macro DB, 2010 (5 MDPs)
1869	8	14	7	MM	Chimara	40,299	19,656	± 14.8	5,8	± 0.00	Thess. Macro DB, 2010 (6 MDPs)
1869	9	1	8	MM	Durres	41,310	19,446		5,9		Thess. Macro DB, 2010 (1 MDPs)
1869	12	1	9	MM	Marmaris	36,919	28,172	± 13.7	6,5	± 0.10	Thess. Macro DB, 2010 (9 MDPs)
1869	12	28	10	MM	Leukada	38,713	20,688	± 9.1	6,4	± 0.10	Thess. Macro DB, 2010 (6 MDPs)
1870	2	22	7	MM	Makri	36,518	28,750	± 57.3	8,1	± 0.40	Thess. Macro DB, 2010 (3 MDPs)
1870	9	28	9	MM	Durres	41,217	19,487	± 3.0	6,8	± 0.20	Thess. Macro DB, 2010 (4 MDPs)
1871	4	9	7	MM	Corfu	39,564	19,948		5,2		Thess. Macro DB, 2010 (2 MDPs)
1871	11	7	7	EMS	Ahmetbeyli	38,017	27,200		5,3		Taxeidis, 2003 (5 MDPs)
1872	2	11	9	MM	Saghiada	39,565	20,304	± 10.3	5,9	± 0.20	Thess. Macro DB, 2010 (6 MDPs)
1873	2	1	7-8	EMS	Samos	37,797	26,912	± 19.1	6,8	± 0.60	Taxeidis, 2003 (6 MDPs)
1873	7	25	7	MM	Epidauros	37,689	23,091	± 10.9	5,5	± 0.10	Thess. Macro DB, 2010 (3 MDPs)
1873	10	25	8	MM	Zakynthos	37,791	20,999	± 10.9	6,5	± 0.20	Thess. Macro DB, 2010 (9 MDPs)
1874	3	18	7	MM	Eretria	38,461	23,852	± 7.8	5,6	± 0.10	Thess. Macro DB, 2010 (8 MDPs)
1875	11	1	8	EMS	Karaburun	38,558	26,567		5,9		Taxeidis, 2003 (3 MDPs)
1876	6	26	7	MM	Nemea	37,812	22,849	± 11.1	5,8	± 0.00	Thess. Macro DB, 2010 (8 MDPs)
1877	10	13	8	EMS	Kokkari	37,769	26,821	± 4.9	5,7	± 0.10	Taxeidis, 2003 (4 MDPs)
1878	4	19	8	MM	Nicomidia	40,703	29,902	± 13.7	6,5	± 0.10	Thess. Macro DB, 2010 (4 MDPs)
1880	7	29	9	EMS	Menemen	38,626	27,168	± 9.2	5,9	± 0.10	Taxeidis, 2003 (15 MDPs)
1881	4	3	9	EMS	Chios	38,221	26,186	± 3.3	6,3	± 0.20	Taxeidis, 2003 (60 MDPs)
1882	4	1	7	EMS	Mesotopos	39,133	26,000		5,3		Taxeidis, 2003 (3 MDPs)
1883	10	15	9	EMS	Cesme	38,330	26,526	± 12.2	6,8	± 0.20	Taxeidis, 2003 (16 MDPs)

Table 3: *Sample period of historical earthquake entries. The first three columns correspond to the year, month and day of the event, Ix is the maximum observed intensity, Sc the scale used for intensity assessment, Ax the area or locality of maximum observed intensity, Lat & Lon the epicentral coordinates, UnC (km) the uncertainty of epicentral calculation (when available), Mw the equivalent moment magnitude, UnM the uncertainty of calculated magnitude (when available) and Source the database of intensity datapoints.*

Conclusions

The present version of the catalogue for the period 1800-2007 contains 140 major shallow historical events with Mw≥5.5 and 6494 instrumental events with Mw≥4. Some historical earthquakes are located along the Hellenic Arc and many have occurred at the Ionian islands – western Greece – southern Albania area. Another set of historical earthquakes is present in the eastern Aegean islands and western Turkey. In the 20th century shallow and intermediate events are present. Most of the shallow earthquakes are located parallel to the Hellenic Arc and intermediate earthquakes are mainly constrained within the back-arc region. The Gulf of Corinth and the area along the westward elongation of the North Anatolia Fault into the Aegean have been extensively active during the instrumental period. The addition of 22 years of seismicity (1986-2007) did not affect the general seismicity pattern of Greece. However, recent seismicity clusters were identified in regions with lack of previous significant activity (Kozani-Grevena 1995, Athens 1999).

Concerning the instrumental period, Mw was calculated for all the events of the catalogue and maximum observed intensities, when available, were also incorporated.

The historical earthquake catalogue is limited mainly to shallow, damaging or destructive earthquakes, that is to earthquakes that have produced noteworthy effects. Their maximum intensities and related Mw are in good agreement with those of the 20th century.

References

Alsan, E., Tezucan, L. and Bath, M., 1975. An earthquake catalogue for Turkey for the interval 19131970, Common Rep. 75 Kandilli Turkey Obs., seism: Inst. Uppgala, Sweden.

Crampin, S. and Ucer, S. B., 1975. The seismicity of the Marmara Sea region of Turkey, Geophys. J. R. Astr. Soc., 40, 269-288.

Douglas, A., 1967. Joint Epicenter Determination, Nature, 215, 47-48.

Galanopoulos, A. G., 1953. Katalog der Erdbeben in Griechenland fuer die Zeit von 1879 bis 1892,Annls Geol. Pays hell., 5, 114-229.

Galanopoulos, A. G., 1960. A Catalogue of shocks with I_0≥VI or M≥5 for the years 1801-1958, Seismological Laboratory, Athens University, 119 pp.

Galanopoulos, A. G., 1977. On the difference in the seismic risk for normal and tall structures at the same site, Nat. Obs. Athens, 33 pp.

Herrin, E., Tucker, W., Taggart, D., Gordon, W. and Lodbell, J. L., 1968. Estimation of source focus P travel times. Bull. Seism. Soc. Am., 58, 1273-1291.

Kárnik, 1969. Seismicity of the European Area, Part I, Academia, Praha.

Makropoulos, K. C., 1978. The statistics of large earthquake magnitude and an evaluation of Greek seismicity, PhD thesis, Edinburgh University, 193 pp.

Makropoulos, K.C. and Burton, P.W., 1981. A catalogue of Seismicity in Greece and the Adjacent Areas, Geophys. J. R. Astr. Soc., 65, 741-762, and Microfiche GJ65/1.

Makropoulos, K.C., Drakopoulos, J. and Latoussakis, J.B., 1989. A revised and extended earthquake catalogue in Greece since 1900. Geophys. J. Int. 98, 391-394.

Papazachos, B. C. and Cornninakis, P. E., 1982. A catalogue of earthquakes in Greece and the surrounding area for the period 1901-1980, Publ. Univ. of Thessaloniki, Geophys. Lab., 5, 1-146.

Papazachos, B.C. and Papazachou, C.B. The earthquakes of Greece. Ziti Publ., Thessaloniki 1989 (in greek, 354p.), 1997 (304p.), 2003 (in greek, 286p.)

Schmidt, J., 1879. Studien ueber Erdbeben, Leipzig.

Scordilis, E., M., 2006. Empirical global relations converting MS and mb to moment magnitude. Journal of Seismology, 10, 225–236.

Shebalin, N. V., Karnik, V. and Hadjievski, D. (eds), 1974. Balkan Region - Catalogue of Earthquakes, UNESCO Project Office, Skopje.

Stepp, J. C., 1971. An investigation of earthquake risk in the Puget Sound area by use of the type I distribution of largest extrmes. PhD thesis, Pennsylvania State University, 131pp.

Taxeidis, K., 2003. Study of historical seismicity of the Eastern Aegean Islands. PhD thesis, Athens Univ., 300p. (in greek).

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