

Seismic Intensity maps in Greece since 1953 using GIS techniques

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Introduction

In order to evaluate the occurrence of large earthquakes and associated ground motions, appropriate maps have been published for several countries of the world. These maps are constructed from a good quality data base of earthquake intensities. Earthquake intensity is a numerical value assigned for every place, village or town, according to the effects of an earthquake on people and their works and on the natural environment. Although the development of seismological instruments and instrumental techniques in the past 100 years has been notable, earthquake intensity information is a unique and valuable data source for the researcher seismologist, the structural engineer, the insurance agent and the earth scientist. Moreover, the knowledge of macroseismic intensities and the visualization of its spatial distribution are of great importance for earthquake hazard studies.

In this study, we directly map the macroseismic intensities distribution across Greece. We use the intensity E.M.S. - 1992 scale for 151 earthquakes located in the broader area of Greece, as routinely they have been observed by the Institute of Geodynamics of the National Observatory of Athens, for earthquake damage since 1953 (Figure 1).

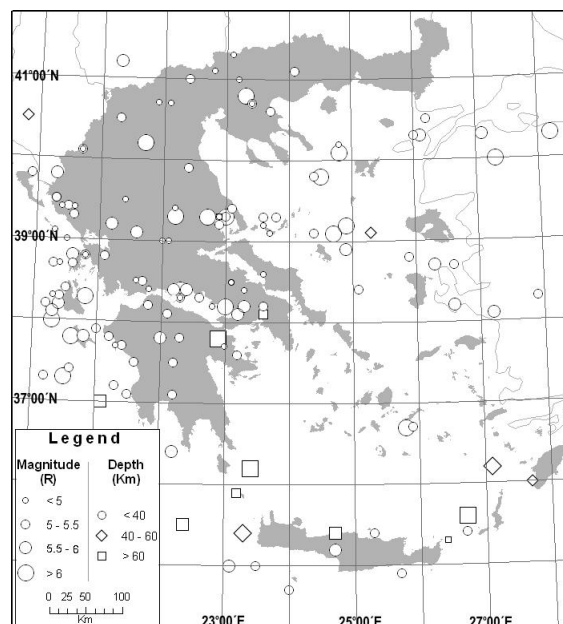


Figure 1. Spatial distribution of the 151 earthquakes used in this study

The Data

The Institute of Geodynamics of the National Observatory of Athens, since its establishment in 1893, collects macroseismic information for strong earthquakes affecting the area of Greece. However, till 1950 this task was not organized systematically. During the decade of the 50's the Institute of Geodynamics established a network of villages/towns in the country, which has been reorganized during the 80's, to which the Institute of Geodynamics sent questionnaires immediately after each strong earthquake. The questionnaire contains important queries about earthquake effects to individuals, to the natural environment as well as to the existing buildings that enable a seismologist to evaluate the intensity of the earthquake in all parts of the shaken area. The returned completed earthquake questionnaires are analysed by the Institute of Geodynamics and intensities are assigned on the basis of the effects at each village/town. Intensities till 1995 were reported using the Modified Mercalli Intensity Scale, since then in the E.M.S. – 1992 scale (Grunthal, 1993). In order to have a homogeneous data set all the intensities were transformed in E.M.S – 1992 scale. Sometimes isoseismal maps were also constructed for earthquakes felt over large areas. These descriptions and maps are done regularly and published in the Monthly Seismological Bulletins of the Institute of Geodynamics.

In this work a digital database has been organized, which contains intensity lists of 146 earthquake cases, corresponding to 151 earthquakes that occurred in Greece and adjacent areas since 1953, having depths down to 150Km and surface magnitudes greater than 4.4. These events are listed in Table 1 and are plotted in Figure 1. Although some events occurred outside the Greek territory, they are included in this atlas, as they were strongly felt in many areas of Greece. Moreover, a digital database of the geographical coordinates of 3360 villages and towns receiving and replying, during the above time period, to macroseismic questionnaires were also organized (Fig. 2). The Monthly Bulletins of the Institute of Geodynamics were used to select the earthquakes and to prepare lists of intensities. In total this database contains 29.530 intensities information.

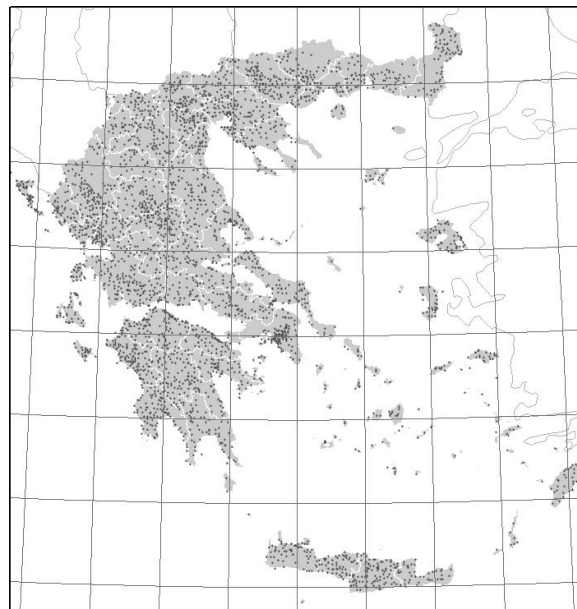


Figure 2. Spatial distribution of the 3360 villages and towns for which macroseismic information are included in the database

Methodology

Several intensity maps for independent earthquakes affecting different places of Greece have been published regularly by the Institute of Geodynamics or by other researchers in the form of atlases (Shebalin, 1974; Papazachos et al., 1982; 1997; Schenkova et al., 2005), However the only published attempt to draw a map of macroseismic intensities covering ;the whole country was that by Drakopoulos and

Makropoulos 1982, who provided a revised maximum intensity map of Greece for the period 1700-1981.

In this work an attempt is made to produce seismic intensity maps for the whole of Greece, by modern GIS techniques based on a complete digital dataset. In order to create a map of maximum intensity for Greece, various spatial interpolation methods were implemented. With this flexible method it was possible to produce maps by taking into account different values like the maximum intensity, the mean intensity of a number of maximum values etc and to plot them with different approaches as at every point-village or at the center of a grid having sides 5km by 5 km covering Greece or by administrative limits (municipalities) and also to produce different maps according to the distribution of the focal depth.

The general concept of all these methods is based on the effort to estimate values on every location (unmeasured location) of the study area according to the values of the surrounding measured values. The general formula for the interpolators is determined as a weighted summation of the measured data:

where $I(s_0)$ the maxIntensity at the prediction location, $I(s_i)$ is the measured maxIntensity at the i^{th} location, λ_i is the unknown weight for the measured maxIntensity at the i^{th} location, and N is the number of the measured values.

The different techniques that were implemented use the technology of Geographical Information Systems (GIS), which is an advanced and efficient way to tackle and analyze spatial data. The flow diagram of Figure 3 presents the proposed methodology.

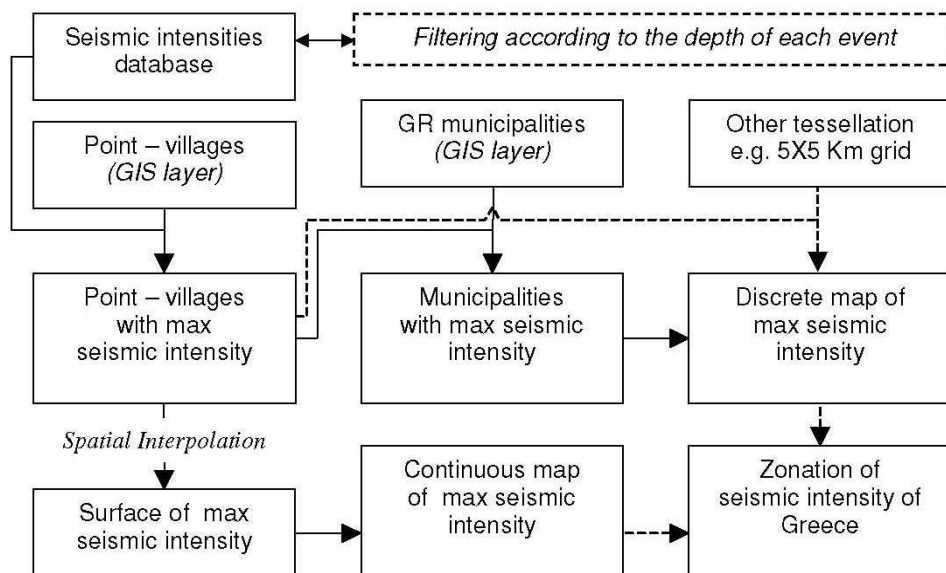


Figure 3. The flow diagram of the proposed methodology

Figure 4 presents the results of IDW Spatial Interpolation method, for shallow events (depth $\leq 60\text{km}$) and in Figure 5 for deep events (depth $> 60\text{km}$). According to this method the weight of a measured point depends on the distance to the prediction location (Watson and Philip, 1985). Thus, close measured points have more influence in the final prediction than distant ones.

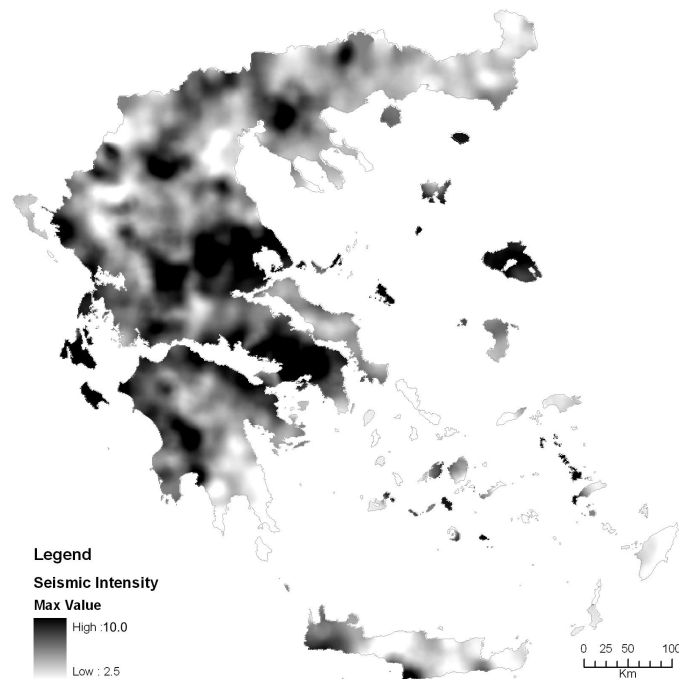


Figure 4. Maximum intensities map of Greece, shallow events (depth ≤ 60 km).

Furthermore, the creation of seismic intensity maps with the use of Greek municipalities (named “Kapodistrias” plan) as spatial reference units was attempted. For this purpose, the maximum-recorded intensity value for a point-village inside each municipality was assigned as the representative maximum intensity value for the municipality. The cartographic representation of these values is presented in Figure 6.

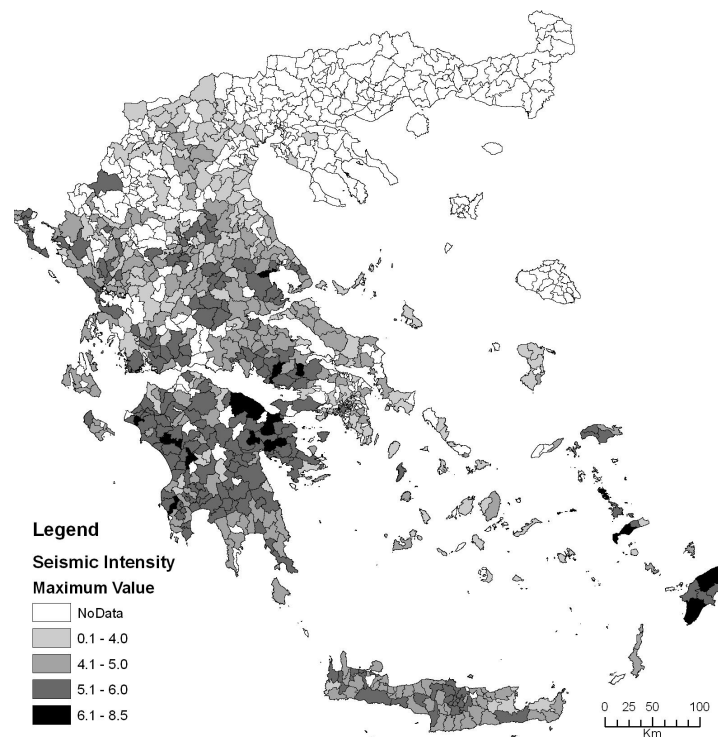


Figure 5. Maximum intensities map of Greece, deep events (depth < 60 km).

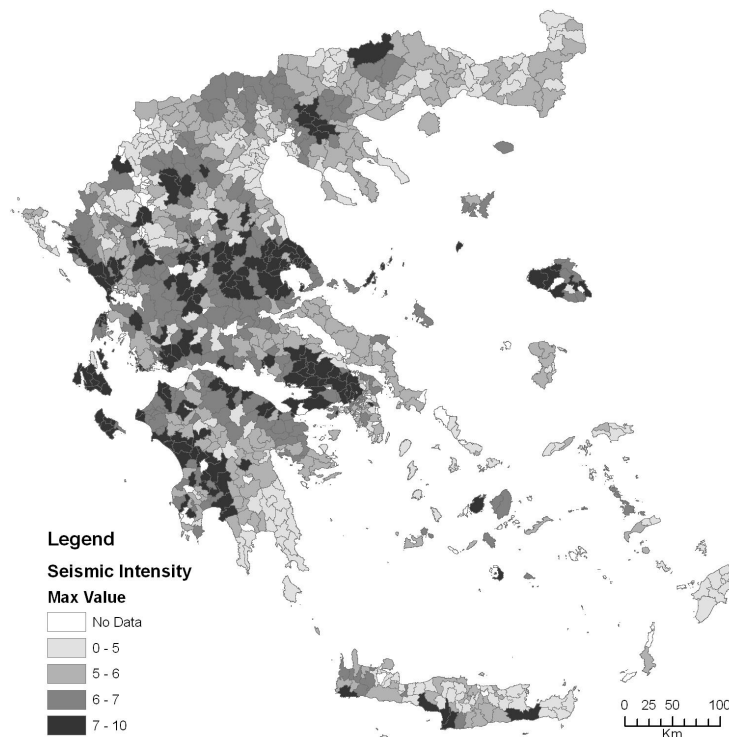


Figure 6. Maximum intensities map by municipalities area, shallow events (depth ≤ 60 km).

Conclusions

During the past 50 years for the shallow events, about 80,5% (831 of 1033) of the municipalities in Greece experienced MM intensity equal to or greater than 5 (≥ 5) while 54,2% (559 of the 1033) have had intensities equal to or larger than 6 (≥ 6). It was estimated that a total area of 7000km², which corresponds to 5% of the total area of the country, presents intensities between 7 and 10, while 19.8% (26000km²) lied between maximum macroseismic intensities of 6 and 7. Additionally, a large percentage of the country (45.8%), which is estimated to occupy an area of 60000km², has experienced maximum seismic intensities between 5 and 6. Finally 38000km² of Greece (29%) had maximum intensities lower than 5. Concerning the deep events 318 (out of 1033) municipalities (a percentage of 31%) intensities greater than 5 (≥ 5) have been reported.

The most seismically active areas of the Greek territory are the Ionian Islands (especially Kefhalonia, Zakynthos and Ithaca) western Epirus and western Peloponnesus as well as parts of the western and southern Crete. These areas are located along the active subsiding zone of the Hellenic arc. Additionally, significantly high macroseismic intensities for the study period characterize Lesbos Island to the east, an extensive area around the city of Athens, a large part of Thessaly and the region around the Gulf of Corinth rift.

These maps are a compilation of past earthquakes and show the allocation of the observed intensities, so the distributions for future earthquakes may be different from the expected intensities. Moreover, macroseismic observations might be incorporated easily within data management systems in order to combine different information such as geological characteristics of the site, type of soil, observed ground accelerations and extract seismic hazard maps.

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TABLE 1
Information on the earthquakes for which macroseismic information are given

MAGNI DATE TUDE	ORIGIN		GEOGRAPHICAL		DEPTH		MEZOSEISMAL AREA
	TIME		COORDINATES		Km		
			°N	- °E		Ms	
1953 MAR 18	19 06	13.0	40.00	- 27.30	10	7.0	NORTH AEGEAN SEA
1953 AUG 12	09 23	52.0	38.30	- 20.80	10	7.2	IONIAN ISLANDS
1954 APR 30	13 02	36.0	39.30	- 22.20	10	6.9	THESSALY
1955 APR 19	16 47	19.0	39.40	- 23.10	10	6.0	THESSALY
1956 JUL 09	03 11	40.0	36.70	- 25.80	10	7.5	SOUTH AEGEAN SEA
1957 MAR 08	12 21	13.0	39.30	- 22.65	10	6.8	THESSALY
1959 MAY 14	06 36	56.0	35.20	- 24.70	10	6.3	CENTRAL CRETE ISLAND
1959 NOV 15	17 08	43.0	37.80	- 20.57	10	6.7	IONIAN ISLANDS
1961 MAY 23	02 45	20.0	36.70	- 28.50	65	6.5	DODECANESE ISLANDS
1962 AUG 28	10 59	56.0	37.80	- 22.90	100	6.5	PELOPONNESUS
1964 JUL 17	02 34	26.7	38.05	- 23.60	150	5.7	CENTRAL-WESTERN GREECE
1964 OCT 06	14 31	23.0	40.30	- 28.20	10	6.5	ASIA MINOR
1965 MAR 09	17 57	54.5	39.30	- 23.80	10	5.9	NORTH AEGEAN SEA
1965 MAR 31	09 47	26.3	38.40	- 22.30	10	6.5	CENTRAL GREECE
1965 APR 05	03 12	54.6	37.75	- 22.00	10		PELOPONNESUS

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								6.1	
1965	JUL	06	03	18	41.10	38.40	-	22.40	CENTRAL GREECE
								6.2	
1965	AUG	23	14	08	58.6	40.50	-	26.20	MACEDONIA - THRACE
								5.5	
1965	DEC	20	00	08	16.3	40.20	-	24.80	MACEDONIA - THRACE
								5.2	
1966	JAN	02	23	12	19.0	37.73	-	23.02	N-E PELOPONNESUS
								5.2	
1966	FEB	05	02	01	44.0	39.05	-	21.61	WESTERN GREECE
								6.4	
1966	SEP	01	14	22	59.8	37.47	-	22.15	CENTRAL PELOPONNESUS
								5.9	
1966	OCT	29	02	39	28.3	38.81	-	21.07	WESTERN GREECE
								6.0	
1967	JAN	04	05	58	54.1	38.40	-	21.83	PELOPONNESUS
								5.4	
1967	FEB	09	14	08	30.0	39.43	-	20.46	EPIRUS
								5.8	
1967	MAR	04	17	58	04.1	39.10	-	24.65	NORTH AEGEAN SEA
								6.8	
1967	MAY	01	07	08	56.7	39.86	-	20.77	WESTERN GREECE
								6.4	
1968	FEB	19	22	45	43.1	39.21	-	24.91	NORTH AEGEAN SEA
								7.2	
1968	MAR	28	07	40	01.1	37.75	-	20.82	PELOPONNESUS
								6.1	
1968	JUL	04	21	47	52.7	37.55	-	23.24	PELOPONNESUS
								5.5	
1969	OCT	13	01	02	31.9	39.82	-	20.32	EPIRUS
								6.2	
1970	MAR	28	21	02	23.0	39.16	-	29.42	WESTERN ANATOLIA
								7.6	
1970	APR	08	13	50	29.7	38.32	-	22.60	GULF OF CORINTH
								5.8	
1972	MAY	08	09	20	52.1	41.89	-	23.62	NORTHERN GREECE
								5.6	
1972	AUG	12	23	47	57.7	41.07	-	22.82	MACEDONIA
								4.9	
1972	SEP	13	04	13	21.5	37.81	-	22.32	PELOPONNESUS
								5.9	
1972	SEP	17	14	07	13.1	38.12	-	20.25	IONIAN ISLANDS
								6.4	
1972	OCT	30	14	32	10.2	38.19	-	20.16	IONIAN ISLANDS
								5.7	
1972	NOV	24	03	48	30.7	39.51	-	20.28	EPIRUS
								5.7	
1972	DEC	05	12	00	12.5	39.18	-	23.56	CENTRAL GREECE
								5.0	
1973	JAN	10	03	24	09.3	37.71	-	21.32	PELOPONNESUS
								5.2	
1973	MAR	06	10	21	21.7	38.57	-	23.64	CENTRAL GREECE
								4.4	
1973	JUL	14	12	38	17.0	37.76	-	21.17	PELOPONNESUS
								5.6	
1973	NOV	4	15	52	13.3	38.73	-	20.32	IONIAN ISLANDS
								6.0	
1973	NOV	4	16	11	37.5	38.70	-	20.37	
								24	
								5.2	
1973	NOV	29	10	57	41.0	35.02	-	23.51	CRETE ISLAND
								6.0	
1973	DEC	05	03	50	51.4	35.25	-	26.39	CRETE ISLAND
								68	
								5.4	
1974	JUN	22	23	30	12.0	41.25	-	23.12	MACEDONIA
								12	
								5.1	

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1974 JUL 09	02 32 06.3	36.32 - 29.17	5	DODECANESE ISLANDS
			5.6	
1974 NOV 14	13 22 33.3	38.46 - 23.08	5	CENTRAL GREECE
	14 26 48.7	38.46 - 23.08	5.2	
			5	
	15 29 44.4	38.52 - 23.09	5.2	
			5	
			5.3	
1975 JAN 8	19 32 34.9	38.17 - 22.80	25	CENTRAL GREECE
			5.2	
1975 MAR 17	05 35 19.6	40.29 - 26.00	26	NORTHERN GREECE
			5.6	
1975 MAR 27	05 15 10.9	40.31 - 26.11	16	NORTH-EAST GREECE
			6.1	
1975 APR 04	05 16 18.7	38.13 - 22.07	33	CENTRAL GREECE
			5.7	
1975 JUN 30	13 26 57.1	38.48 - 21.59	17	WESTERN GREECE
			5.4	
1975 DEC 31	09 45 45.6	38.50 - 21.71	5	WESTERN GREECE
			5.5	
1976 FEB 22	12 02 54.1	39.37 - 22.19	32	CENTRAL GREECE
			5.1	
1976 MAY 11	16 59 46.8	37.33 - 20.22	20	IONIAN SEA
			5.8	
1977 FEB 24	20 47 15.7	38.34 - 27.87	11	NORTH AEGEAN SEA
			5.5	
1977 MAY 13	18 17 47.4	39.12 - 23.66	20	AEGEAN SEA
			5.2	
1977 SEP 11	23 19 22.9	34.99 - 23.05	5	CRETE ISLAND
			6.4	
1977 NOV 28	02 59 13.8	36.04 - 27.71	51	DODECANESE ISLANDS
			5.7	
1978 JAN 29	10 23 42.3	34.90 - 25.69	5	CRETE ISLAND
			5.8	
1978 APR 27	08 33 27.8	38.97 - 21.97	5	CENTRAL GREECE
			4.9	
1978 MAY 23	23 34 13.1	40.68 - 23.44	10	NORTHERN GREECE
			6.0	
1978 JUN 20	20 03 22.4	40.82 - 23.28	4	NORTHERN GREECE
			6.6	
1978 JUL 4	22 23 25.8	40.95 - 23.19	5	NORTHERN GREECE
			5.3	
1979 FEB 16	04 28 19.0	36.74 - 25.91	5	AEGEAN SEA
			5.5	
1979 APR 15	06 19 42.0	42.06 - 19.14	10	MONTENEGRO
			7.1	
1979 JUN 14	11 44 44.9	38.70 - 26.59	7	NORTH AEGEAN SEA
			6.0	
1979 JUN 15	11 34 13.6	34.68 - 24.03	5	CRETE ISLAND
			5	
			6	
1979 JUL 23	11 41 50.1	35.37 - 26.71	20	CRETE ISLAND
			5.6	
1979 AUG 31	17 24 11.1	40.65 - 23.42	5	NORTH AEGEAN SEA
			4.8	
1979 NOV 6	05 26 17.7	39.39 - 20.58	5	EPIRUS
			5.4	
1979 NOV 11	01 18 6.2	39.43 - 20.41	5	EPIRUS
			5.2	
1980 FEB 28	23 45 15.8	38.36 - 23.27	5	CENTRAL GREECE
			4.8	
1980 JUL 4	20 20 16.2	39.28 - 22.91	71	CENTRAL GREECE
			5.1	
1980 JUL 10	19 39 3.9	39.27 - 22.97	22	CENTRAL GREECE

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							5.5	
1980	JUL	09	02	11	55.8	39.28 - 22.99	5	CENTRAL GREECE
							6.8	
1980	AUG	11	09	16	00.2	39.28 - 22.87	7	CENTRAL GREECE
							5.3	
1981	FEB	24	20	53	37.9	38.17 - 22.97	14	EAST GULF OF CORINTH
							6.8	
1981	FEB	25	02	35	53.3	38.09 - 23.17	13	
							6.4	
1981	MAR	4	21	58	06.0	38.20 - 23.26	14	EAST GULF OF CORINTH
							6.3	
1981	MAR	10	15	16	15.5	39.45 - 20.28	17	EPIRUS
							5.9	
1981	DEC	19	14	10	52.5	39.13 - 25.30	42	NORTH AEGEAN SEA
							5.9	
1981	DEC	27	17	39	14.5	38.87 - 24.91	25	AEGEAN SEA
							6.4	
1982	JAN	18	19	27	24.9	39.78 - 24.48	5	NORTH AEGEAN SEA
							6.8	
1982	JUN	22	03	04	28.4	37.04 - 21.06	102	PELOPONNESUS
							6.3	
1982	NOV	16	23	41	27.5	40.54 - 19.80	49	SOUTH ALBANIA
							5.8	
1983	JAN	17	12	41	30.9	37.97 - 20.25	9	IONIAN ISLANDS
							6.7	
1983	MAR	16	21	19	39.1	38.79 - 20.81	9	EPIRUS
							5.5	
1983	MAR	19	21	41	49.2	35.35 - 25.30	28	CRETE ISLAND
							5.7	
1983	MAR	23	19	03	59.8	38.78 - 20.81	10	WESTERN GREECE
							5.4	
1983	MAR	23	23	51	07.6	38.19 - 20.40	10	WESTERN GREECE
							6.2	
1983	JUL	05	12	01	30.7	40.27 - 27.13	35	SOUTH BULGARIA
							6.4	
1983	AUG	06	15	43	53.3	40.08 - 24.81	22	NORTHERN GREECE
							7.1	
1984	JUN	21	10	43	46.2	35.36 - 23.31	46	CRETE ISLAND
							6.4	
1984	JUL	9	18	57	10.9	40.68 - 21.90	5	MACEDONIA
							5.4	
1984	OCT	25	14	38	25.5	40.49 - 21.32	20	NORTH-WESTERN GREECE
							5.6	
1985	APR	30	18	14	12.8	39.24 - 22.89	13	CENTRAL GREECE
							5.8	
1985	AUG	31	06	03	44.8	39.01 - 20.48	5	EPIRUS
							5.3	
1985	SEP	7	10	20	49.3	37.24 - 21.25	5	WEST PELOPONNESUS
							5.7	
1985	NOV	09	23	30	45.6	41.11 - 24.05	23	NORTHERN GREECE
							5.6	
1986	FEB	18	14	34	4.2	40.70 - 22.13	5	MACEDONIA
							5.1	
1986	MAR	25	01	41	36.8	38.38 - 25.13	16	CENTRAL GREECE
							5.7	
1986	SEP	13	17	24	33.8	37.10 - 22.19	5	SOUTH PELOPONNESUS
							6.0	
1986	DEC	17	21	18	33.1	39.76 - 19.90	5	NORTH-WESTERN GREECE
							5.6	
1987	MAY	29	18	40	33.2	37.53 - 21.60	29	EAST PELOPONNESUS
							5.5	
1988	MAY	18	05	17	42.7	38.35 - 20.47	5	CENTRAL-WESTERN GREECE
							5.8	
1988	OCT	16	12	34	5.4	37.90 - 20.96	4	WEST PELOPONNESUS
							6.0	

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1989 MAR 19	05 37 00.2	39.29 - 23.57	13 5.8	AEGEAN SEA
1989 SEP 19	07 57 07.6	39.48 - 21.36	5 5.0	WESTERN GREECE
1990 DEC 21	06 57 43.3	40.95 - 22.43	5 5.9	MACEDONIA
1992 JAN 23	04 24 16.7	38.28 - 20.41	5 5.5	WESTERN GREECE
1992 JAN 23	06 27 39.2	38.28 - 20.27	5 5.1	
1992 JUL 23	20 12 45.2	39.82 - 24.43	19 5.5	NORTHERN GREECE
1992 NOV 06	19 08 8.4	38.09 - 27.19	39 6.2	AEGEAN SEA
1992 NOV 18	21 10 43.1	38.27 - 22.33	23 5.7	GULF OF CORINTH
1992 NOV 21	05 07 19.0	35.51 - 22.38	93 6.3	SOUTH-CENTRAL GREECE
1993 MAR 05	06 55 6.5	37.07 - 21.46	5 5.8	SOUTH PELOPONNESUS
1993 MAR 18	15 47 1.5	38.26 - 22.20	51 5.4	CENTRAL GREECE
1993 MAR 26	11 58 18.3	37.65 - 21.44	5 5.5	WEST PELOPONNESUS
1993 JUN 13	23 26 40.0	39.25 - 20.57	5 5.9	WESTERN GREECE
1993 JUL 14	12 31 50.2	38.16 - 21.76	13 5.6	WESTERN GREECE
1993 AUG 26	10 03 53.7	36.66 - 28.42	17 5.7	DODECANESE ISLANDS
1994 FEB 25	02 30 49.7	38.73 - 20.58	5 5.8	NORTH-WESTERN GREECE
1994 APR 16	23 09 36.4	37.43 - 20.58	30 5.8	WESTERN GREECE
1994 MAY 23	06 46 16.3	35.40 - 24.73	81 6.1	SOUTHERN GREECE
1994 MAY 24	02 05 37.6	38.71 - 26.32	12 6.1	AEGEAN SEA
1994 SEP 01	16 12 41.6	41.15 - 21.26	5 6.4	SOUTH YUGOSLAVIA
1995 MAY 04	00 34 10.6	40.57 - 23.69	7 5.5	MACEDONIA
1995 MAY 13	08 47 17.0	40.18 - 21.71	39 6.6	NORTH-WESTERN GREECE
1995 JUN 15	00 15 51.0	38.37 - 22.15	26 6.1	WEST GULF OF CORINTH
1996 JUL 20	00 00 43.1	36.21 - 27.14	45 6.4	DODECANESE ISLANDS
1996 JUL 26	18 55 50.4	40.05 - 20.68	5 5.4	NORTH-WESTERN GREECE
1996 AUG 05	22 46 43.0	40.07 - 20.67	5 5.7	NORTH-WESTERN GREECE
1997 OCT 13	13 39 39.2	36.41 - 22.18	6 6.1	NORTHERN GREECE
1997 OCT 21	17 57 45.4	38.98 - 22.11	5 4.7	CENTRAL GREECE
1997 NOV 05	21 10 28.3	38.34 - 22.31	5 5.4	NORTHERN GREECE
1997 NOV 12	16 26 56.6	39.10 - 20.27	5 5.3	NORTH-WESTERN GREECE
1997 NOV 14	21 38 52.7	38.80 - 25.87	25 5.9	NORTHERN GREECE
1997 NOV 18	13 07 36.9	37.26 - 20.49	5 6.6	WESTERN PELOPONNESUS
1999 SEP 07	11 56 50.5	38.15 - 23.60	29	CENTRAL GREECE

Ref: <to be completed by the Local Organizing Committee>

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Hersonissos, Crete, Greece, 7-12 September 2008

								5.9	
2001	JUL	26	00	21	39.3	39.05	-	24.35	19
									5.8
2002	JAN	22	04	53	54.3	35.56	-	26.73	104
									6.6
2002	MAY	21	20	53	30.8	36.57	-	24.31	97
									5.6
2003	JUN	09	07	06	40.7	39.94	-	22.35	18
									5.5
2004	NOV	04	06	22	37.4	35.86	-	23.23	95
									5.5
2005	OCT	20	21	40	03.6	38.16	-	26.62	25
									6.1
2006	JAN	08	11	34	54.0	36.21	-	23.41	69
									6.8