Site effect estimation based on source and path modeling of macroseismic intensities in the area of Greece

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SUMMARY – The macroseismic intensity of an earthquake in a specific site depends on three main factors: the properties of the source, the wave path from the source to the site, and the properties of the site. On the basis of a previous work, a modeling of the source and of the wave path was performed for 113 earthquakes in Greece, using 20475 macroseismic intensities observed at 3967 sites. Based on this modeling, the theoretical intensities at these sites were computed and the difference between the theoretical and the observed intensity was considered to be a «site effect». Spatial clustering of positive residuals (amplification effect) are observed in some regions with dimensions of the order of several tenths of kilometers as well as of negative residuals in some other regions of similar dimensions. In many cases, however, sites with positive and negative residuals are very close, which indicates that site effects are phenomena of very local scale.

KEYWORDS: Macroseismic intensity, site effect, wave path modeling.

1. Introduction

Site effects are considered to be the influence of local geological and geomorphological characteristics to the seismic motion at a site. Four experimental methods are usually applied in order to estimate the site effect /1/. In the first two, the ground motion characteristics are studied using weak or strong ground motion data. The third method is based on the use of microtremor data, while for the last one macroseismic intensity data are employed. The most common approach in site effect estimations is the use of ground motion data /2, 3, 4, 5, 6, 7, 8, 9/. In addition, microtremor data have been also occasionally correlated with site conditions. This method has been widely used in Japan and to a less extent in USA and Europe /3, 10/. However, macroseismic intensity data are not frequently used for similar estimations. This is mainly due to the difficulties in modeling the macroseismic field in order to estimate the theoretically expected intensity at a site and correct the observed intensity values /11, 12, 13/.

Macroseismic intensities in Greece have been used by various scientists, mainly for attenuation studies or for magnitude estimation of historical earthquakes /14, 15, 16, 17, 18, 19/. In order to estimate site effects, Kouskouna et al. /20/ used macroseismic data for two events and correlated macroseismic intensities with areas of deep alluvial fills, in comparison with the response of bedrock formations.

In the present study, an attempt is made to determine site effects in the area of Greece using macroseismic intensity data. In order to remove the source and path effects, the data were initially processed using a model which considers parameters which depend on the seismic source (magnitude, focal depth, radiation pattern) and on the wave path (epicentral distance, attenuation, geometrical spreading). Theoretical macroseismic intensities were calculated using this model and the difference between the observed and calculated values was attributed to site effects.

2. Data used

The macroseismic data used in the present study are the observed macroseismic intensities from 113 large shallow earthquakes with magnitude $M_s \geq 5.0$ that occurred in the area of Greece during the period 1950-1993. The source of the data is the macroseismic intensity observations, in the MM scale, published in the Bulletins of the Seismological Institute of the National

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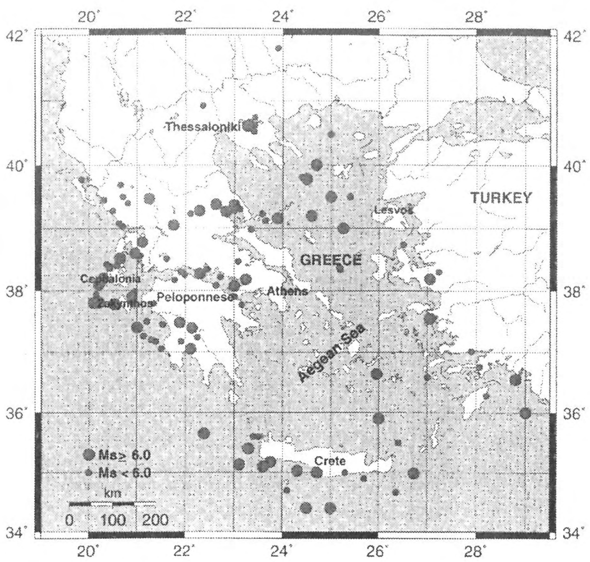

Fig. 1 – Map of the epicenters of the earthquakes for which data were used in the present study.

Observatory of Athens (BSINOA). Information on the earthquakes for which data have been used, such as origin time, latitude and longitude of the epicenter, focal depth and surface wave magnitude, M_s, were taken from the catalogue of Comninakis and Papazachos /21/ for the time period 1901-1985 and from the Annual Bulletins of the Geophysical Laboratory of the University of Thessaloniki for the period 1986-1993. Figure 1 shows a map of the epicenters of the earthquakes for which data have been used in the present study.

A data base was created which originally consisted of three separate data sets. The first one included the data as they were originally reported by BSINOA (one data file for each earthquake with a header giving information on the date, origin, epicentral coordinates and M_s of the earthquake and a list of the macroseismic intensities, names of the villages and the county that each one belongs). The second set included the coordinates of the Greek villages (Ordinance Survey) and the third set included the boundaries of all the counties in Greece in latitude and longitude (kindly offered by the Hellenic Corporation of Local Authority and Development). These three data sets were combined in order to create a unified database of 113 files (one for each earthquake) with a total of 20475 macroseismic observations from 3967 sites.

Information on the data used in the present study is given in Table 1. Columns two to five show the date, coordinates of the epicenter and the surface wave magnitude, M_s, for each of the 113 earthquakes. The sixth column gives the number of the macroseismic observations with epicentral distances less than 100km, and the last column gives the total number of macroseismic observations for each earthquake.

Table 1 – *Information on the date, geographic coordinates, ϕ_N^0, λ_E^0, of the epicenter, surface wave magnitude, M_s, number of macroseismic observations with epicentral distance less then 100 km, NO, and total number of macroseismic observations, SNO, for each shallow earthquake.*

No	Date	ϕ_N^0	λ_N^0	M_s	NO	SNO
1	27-Jun-52	40.62	23.42	5.0	29	31
2	13-Oct-52	38.98	23.34	5.3	37	42
3	17-Dec-52	34.40	24.50	7.0	12	114
4	07-Feb-53	34.70	24.10	5.8	22	37
5	13-Jun-53	38.08	22.63	5.5	28	36
6	09-Aug-53	38.52	20.64	6.4	33	52
7	05-Sep-53	37.90	23.00	5.8	48	67
8	14-Sep-53	38.56	21.07	5.7	21	41
9	21-Oct-53	38.60	20.96	6.3	23	48
10	30-Apr-54	39.28	22.29	7.0	135	207
11	03-Jan-55	39.23	22.10	5.6	77	87
12	28-Mar-55	37.79	21.35	5.7	52	52
13	13-Apr-55	37.24	22.25	5.9	62	73
14	19-Apr-55	39.37	23.00	6.2	62	94
15	21-Apr-55	39.31	23.12	5.8	23	47
16	16-Jul-55	37.55	27.05	6.9	29	57
17	09-Jul-56	36.64	25.96	7.5	54	106
18	30-Jul-56	35.90	26.00	6.0	8	21
19	08-Mar-57	39.38	22.63	6.8	259	360
20	24-Apr-57	36.00	29.00	6.8	8	52
21	25-Apr-57	36.55	28.80	7.2	33	77
22	21-May-57	39.28	23.00	5.6	53	68
23	16-Jan-58	39.50	25.40	5.7	7	10
24	17-Jul-58	40.74	23.42	5.6	48	50
25	27-Aug-58	37.40	21.00	6.4	19	46
26	14-May-59	35.00	24.72	6.3	125	149
27	10-Jun-59	35.60	23.40	5.5	13	20
28	15-Nov-59	37.78	20.53	6.8	50	235
29	23-Feb-60	39.03	20.69	5.6	58	67
30	13-Jul-60	40.52	23.40	5.4	72	78
31	05-Nov-60	39.08	20.62	5.7	96	109
32	02-Oct-61	37.17	21.91	5.7	113	152
33	10-Apr-62	37.80	20.10	6.3	21	122
34	06-Jul-62	37.81	20.20	6.1	19	86
35	29-Apr-64	39.12	23.64	5.6	128	327
36	09-Mar-65	39.16	23.89	6.1	76	504
37	05-Apr-65	37.48	21.88	6.1	376	603
38	09-Apr-65	35.03	24.31	6.1	65	110
39	27-Apr-65	35.60	23.50	5.7	6	43
40	06-Jul-65	38.27	22.30	6.3	338	555
41	20-Dec-65	40.48	25.00	5.6	107	243
42	05-Feb-66	39.05	21.75	6.2	383	548
43	01-Sep-66	37.39	22.14	6.0	227	321
44	29-Oct-66	38.78	21.11	6.0	235	400
45	04-Jan-67	38.25	21.98	5.5	130	135
46	04-Mar-67	39.20	24.60	6.6	24	534
47	01-May-67	39.47	21.25	6.4	249	423
48	19-Feb-68	39.50	25.00	7.1	27	658
49	28-Mar-68	37.80	20.90	5.9	65	175
50	04-Jul-68	37.77	23.15	5.5	261	374
51	31-Oct-68	36.59	27.00	5.7	17	47
52	12-Jun-69	34.40	25.00	6.1	41	62
53	13-Oct-69	39.69	20.65	5.8	177	343
54	04-May-72	35.10	23.60	6.5	31	94
55	29-Nov-73	35.18	23.75	6.0	80	203
56	14-Nov-74	38.47	23.08	5.2	199	257
57	08-Jan-75	38.22	22.72	5.5	276	430
58	31-Dec-75	38.51	21.61	5.7	344	452
59	11-Sep-77	35.13	23.11	6.3	13	39
60	16-Dec-77	38.30	27.23	5.5	18	45
61	29-Jan-78	34.90	25.70	5.7	105	114
62	23-May-78	40.67	23.31	5.8	295	329
63	20-Jun-78	40.61	23.27	6.5	435	960
64	14-Jun-79	38.74	26.50	5.9	106	149
65	23-Jul-79	35.50	26.40	5.5	72	187
66	06-Nov-79	39.45	20.31	5.5	237	275
67	09-Jul-80	39.27	22.83	6.5	575	1008

Table 1 – *(cont).*

No	Date	ϕ_N^0	λ_N^0	M_s	NO	SNO
68	24-Feb-81	38.07	23.00	6.7	515	1216
69	04-Mar-81	38.18	23.24	6.3	295	661
70	10-Mar-81	39.40	20.80	5.6	99	256
71	28-Jun-81	37.80	20.10	5.6	8	54
72	03-Jul-81	39.50	20.70	5.5	180	209
73	19-Dec-81	39.00	25.26	7.2	44	726
74	18-Jan-82	39.78	24.50	7.0	25	718
75	22-Jun-82	37.20	21.30	5.7	120	149
76	17-Jan-83	38.10	20.20	7.0	60	571
77	19-Jan-83	38.10	20.20	5.7	49	70
78	19-Mar-83	35.00	25.30	5.7	80	85
79	23-Mar-83	38.20	20.30	6.2	97	400
80	06-Aug-83	40.00	24.70	6.8	33	467
81	11-Feb-84	38.30	21.90	5.6	160	177
82	21-Jun-84	35.40	23.30	6.2	51	234
83	30-Apr-85	39.30	22.80	5.8	215	348
84	07-Sep-85	37.50	21.20	5.6	165	302
85	09-Nov-85	41.80	23.90	5.5	162	489
86	25-Mar-86	38.34	25.19	5.7	41	98
87	29-Mar-86	38.37	25.18	5.8	45	97
88	13-Sep-86	37.05	22.11	6.0	389	655
89	17-Dec-86	39.77	19.84	5.6	75	134
90	27-Feb-87	38.42	20.36	5.9	56	69
91	29-May-87	37.45	21.53	5.5	119	160
92	10-Jun-87	37.17	21.39	5.5	53	90
93	05-Oct-87	36.28	28.20	5.6	23	27
94	18-May-88	38.36	20.42	5.8	88	206
95	22-May-88	38.39	20.43	5.5	83	112
96	22-Sep-88	37.98	20.95	5.5	106	117
97	16-Oct-88	37.89	20.89	6.0	163	287
98	19-Mar-89	39.23	23.57	5.8	70	147
99	28-Apr-89	37.01	27.90	5.5	13	14
100	20-Aug-89	37.26	21.14	5.9	68	97
101	24-Aug-89	37.94	20.14	5.7	26	61
102	21-Dec-90	40.92	22.36	5.9	218	253
103	19-Mar-91	34.67	26.36	5.8	28	58
104	23-Jan-92	38.40	20.57	5.5	63	77
105	30-Apr-92	34.99	26.72	6.1	23	41
106	23-Jul-92	39.81	24.40	5.5	15	117
107	06-Nov-92	38.19	27.05	6.2	31	69
108	18-Nov-92	38.34	22.44	5.7	268	475
109	21-Nov-92	35.65	22.39	6.3	6	199
110	05-Mar-93	37.05	21.50	5.9	57	65
111	13-Jun-93	39.28	20.49	5.9	123	149
112	14-Jul-93	38.17	21.77	5.5	214	279
113	26-Aug-93	36.75	28.06	5.6	16	18

3. Method Applied

For each site the difference between the observed macroseismic intensity and the theoretical one, calculated by a source and path modeling of the macroseismic field was considered as a site effect. The method applied here for the modeling of the macroseismic intensity field was the one developed by Papazachos /22/. According to this method, the observed macroseismic intensity, I, depends on the source properties, the geometrical spreading, the anelastic attenuation and the properties of the site and is given by the relation:

$$I = I_f + v\log(\sqrt{\Delta^2 + h^2}) + c(\sqrt{\Delta^2 + h^2}) + d \qquad (1)$$

where I_f is the intensity at the source, which represents the «macroseismic size» of the earthquake, Δ is the epicentral distance, v is the geometrical spreading factor, c is the anelastic attenuation coefficient and d is the site amplification factor. According to this method, two alternative models can be applied. The first is based on the hypothesis that seismic energy is isotropically radiated, therefore the isoseismals should have a circular shape (circular model). The second one is based on the hypothesis that the shape of short distance isoseismals is due to anisotropic radiation of seismic energy at the source, while the shape of long distance isoseismals is due to anisotropic radiation and attenuation. This model assumes that the isoseismal at intermediate distances from the epicenter has an elliptical shape, with axes $\alpha > \beta$ and ellipticity e, and therefore is hereafter referred to as «elliptical» model.

The circular model is described by the following relations:

$$I - I_0 = v\log\sqrt{1 + \frac{\Delta^2}{h^2}} + c(\sqrt{\Delta^2 + h^2} - h), \quad \Delta < \Delta_0$$

$$(2)$$

$$I - I_0 = v_L \log\sqrt{\frac{h^2 + \Delta^2}{h^2 + \Delta_0^2}} + v\log\sqrt{1 + \frac{\Delta_0^2}{h^2}} + c(\sqrt{\Delta^2 + h^2} - h), \quad \Delta < \Delta_0$$

where I_0 is the epicentral intensity ($\Delta = 0$), v is the geometrical spreading factor for S waves, v_L is the geometrical spreading factor for L_g waves, h is the macroseismic focal depth, Δ_0 is the critical distance after which L_g waves overtake S-waves and c is the anelastic attenuation coefficient.

For the «elliptical» model these relations are modified for the anisotropic radiation pattern to

$$I - I_{0_{\min}} = v\log\left(S^{1/2}\sqrt{1 + \frac{\Delta^2}{h^2}}\right) + c(\sqrt{\Delta^2 + h^2} - h), \quad \Delta < \Delta_0$$

$$(3)$$

$$I - I_{0_{\min}} = v_L \log\sqrt{\frac{h^2 + \Delta^2}{h^2 + \Delta_0^2}} + v\log\left(S^{1/2}\sqrt{1 + \frac{\Delta_0^2}{h^2}}\right) + c(\sqrt{\Delta^2 + h^2} - h), \quad \Delta < \Delta_0$$

where the «shape» factors, is given by the relation

$$S = 1 - e^2 \cos^2 (\zeta - \phi) \quad 0 \leq S < 1. \qquad (4)$$

and ζ, ϕ, are the azimuths from north of the major axis of the ellipse and the epicenter-site axis, and $I_{0_{\min}}$ is the value of the epicentral intensity for the minor axis of the ellipse.

Papazachos /22/ applied these models to 13,008 intensity observations grouped in 4,228 values and he estimated the macroseismic focal depth, the geometrical spreading factor, the macroseismic size, I_f, the radiation pattern and the anelastic attenuation coefficient for each earthquake. The grouping of the intensity values was made in order to diminish observational errors and mainly site effects.

In the present study, intensity observations were used without grouping the data and the same weight was assigned to each observation. Then, the previously mentioned parameters were recalculated using both the circular and the elliptical model. For both models the values of Papazachos /22/ were accepted for the spreading factor ($v = -3.49$, $v_L = -3.30$) and the value of 100 km was given to the critical epicentral distance, Δ_0. Using the Levenberg-Marquadt method /23, 24/, the parameters I_0, h, for the circular model and $I_{0_{\min}}$, e, ζ, c, for the elliptical model, as well as their corresponding errors, were initially calculated. As a starting value for the attenuation coefficient, the value of –0.003 was adopted /22/.

Constraining the geometrical spreading is necessary if we want to avoid a large trade-off of v with focal depth. On the other hand theoretical and experimental results confirm that geometrical spreading for body waves is constant for the distance range of interest. Recent results for intensity data /25/ confirm this stability for the whole Balkan area. Moreover, although geometrical spreading is constrained, any variability in the energy decay can be adequately modeled by varying the depth. Therefore, we can compute a robust average attenuation curve and hence avoid systematic bias in the relative intensity residual estimation.

For each earthquake, the direction of maximum intensity, ζ (elliptical model) was accepted if the corresponding error was not very large ($\leq 20^o$) and the calculated attenuation coefficient had a value within the range $c = \bar{c} \pm 2\sigma$ (with $\bar{c} = -0.0035$ and $\sigma = 0.0016$), which corresponds to Q_s values down to $\simeq 180$, which are expected for this area /22, 26, 27/. For those earthquakes that did not fulfill these criteria, the mean value of ζ from the surrounding earthquakes was adopted. For each earthquake the parameters $I_{0_{\min}}$, e, c, were recalculated using the elliptical model, keeping constant the direction of maximum intensity, ζ, and using the calculated attenuation coefficient as a starting value. The attenuation coefficient within the range $c = \bar{c} \pm 2\sigma$ were accepted, otherwise the mean value of for the surrounding area was adopted. For the ellipticity, e, the values that were within the range 0.3 to 0.9 were accepted, otherwise the mean value of e of the surrounding area was adopted. For h the values estimated from the circular model were adopted and values that were less than 20 km were accepted, otherwise the mean value of h of the surrounding area was adopted.

In Table 2, a list is given for the final values of azimuth, ζ, attenuation coefficient, c, ellipticity, e, focal depth, h, and macroseismic size, I_f. Values that are in brackets are mean values derived from data of the surrounding earthquakes. Using these calculated values for ζ, c, e, h, and $I_{0_{\min}}$, the macroseismic intensity, I_{cal}, was estimated for the «elliptical» model (equation 3).

Table 2 – *Macroseismic parameters of the 113 earthquakes given in Table 1: azimuth, ζ, attenuation coefficient, c, ellipticity, e, focal depth, h, and macroseismic size I_f.*

No	ζ	c	e	h	I_f
1	(86.8)	–.002949	.713	4.3	9.0
2	(80.4)	–.007288	.351	11.3	9.9
3	(133.7)	(–.001573)	(.820)	2.4	10.3
4	(133.7)	–.001561	(.820)	7.0	10.0
5	(80.4)	–.005304	(.552)	4.4	9.2
6	135.3	–.004425	.879	9.0	10.7
7	(80.4)	–.001827	.642	4.5	9.1
8	(146.0)	(–.0030)	(.727)	6.0	9.3
9	(146.0)	(–.0030)	(.727)	8.1	10.3
10	90.0	–.002634	.563	6.6	11.1
11	92.2	–.006203	.768	(6.6)	10.8
12	250.0	–.007691	(.810)	10.7	10.2
13	(26.5)	–.002171	(.497)	6.0	9.4
14	271.9	–.002399	(.637)	8.1	10.5
15	254.1	–.004455	(.637)	6.7	10.1
16	58.9	–.002778	.641	6.8	11.0
17	68.3	–.007352	(.841)	16.6	12.1
18	(63.6)	–.002569	.841	8.3	10.1
19	109.4	–.001951	.883	5.2	10.8
20	(132.0)	(–.002494)	(.790)	(14.1)	11.6
21	(132.0)	–.002494	.861	14.2	12.4
22	(80.4)	–.004855	(.637)	11.2	10.5
23	(43.5)	–.004440	(.752)	6.9	9.4
24	262.5	–.003302	.670	4.4	8.9
25	161.7	(–.003254)	.731	2.5	9.2
26	134.7	–.006351	.824	5.4	10.0
27	(130.0)	–.004327	(.820)	9.1	10.1
28	119.1	(–.0040)	.784	2.7	10.3
29	159.1	–.003072	.868	3.8	8.7
30	284.0	(–.003384)	(.515)	5.6	9.8
31	152.8	–.004650	.826	7.0	9.6
32	(125.5)	–.003284	.596	7.0	9.6
33	26.4	(–.003269)	(.491)	3.8	10.1
34	9.0	(–.003269)	(.491)	2.3	9.3
35	238.8	(–.003890)	(.302)	8.4	9.8
36	(80.4)	(–.003890)	(.302)	4.6	10.1
37	(125.5)	(–.003284)	.818	3.8	10.0
38	118.5	–.005120	.883	5.7	10.0
39	(130.0)	–.004579	(.820)	7.7	9.8
40	(80.4)	–.001599	.587	5.1	10.0
41	(43.5)	–.001942	(.752)	5.8	9.6
42	(80.4)	–.002537	(.665)	4.7	9.9
43	38.2	–.002818	(.497)	5.5	9.4
44	301.3	(–003000)	.575	5.9	9.6
45	(80.4)	(–.004000)	(.585)	5.1	9.2
46	(43.5)	(–.002306)	(.752)	2.2	9.7
47	154.6	(–.002000)	.693	2.6	9.4
48	(43.5)	–.002306	.567	6.7	11.0
49	(125.5)	(–.001911)	.788	5.5	9.0
50	58.6	–.002145	(.642)	5.7	9.2
51	(63.6)	–.003020	(.670)	1.1	9.3
52	327.9	–.001585	.767	.6	9.0
53	123.5	(–.002000)	.615	7.9	9.7
54	(130.0)	(–.004453)	.812	.7	9.4
55	(130.0)	(–.004453)	(.820)	5.9	9.6
56	(80.4)	(–.004020)	.523	9.2	9.1
57	(80.4)	–.003974	(.552)	6.6	9.2
58	98.4	–.002237	(.585)	2.8	9.2
59	(104.7)	(–.004453)	.503	2.6	9.1
60	(264.8)	–.001818	.896	5.1	9.1
61	(133.7)	–.005962	.743	2.8	9.2
62	74.4	–.003902	.659	8.4	9.1
63	268.4	(–.003384)	.318	6.6	10.0
64	80.1	– 002344	.515	2.0	9.5
65	(63.6)	(–.002569)	.679	3.4	9.0
66	(146.0)	–.001683	.601	2.9	8.7
67	65.4	–.004693	.694	14.1	10.6
68	83.9	–.001927	.510	3.4	10.2

Table 2 – *(cont)*.

No	ζ	c	e	h	I_f
69	84.7	(–.004020)	(.552)	3.1	10.3
70	(146.0)	(–.002000)	.506	2.3	8.9
71	(9.0)	(–.003269)	.411	6.5	9.0
72	(146.0)	(–.002000)	.390	8.6	9.1
73	257.1	–.002362	.893	1.4	11.0
74	39.1	(– 002890)	.752	4.5	10.8
75	301.7	–.004001	.899	8.8	9.6
76	45.0	(–.003269)	(.491)	.7	10.5
77	45.0	–.004377	.491	4.0	9.7
78	(133.7)	(–.006150)	.899	3.5	8.5
79	235.6	(–.003261)	.459	5.5	9.6
80	48.0	(–.002890)	.805	1.6	10.6
81	266.7	–.005408	.534	(10.0)	9.2
82	130.0	(–.004453)	(.820)	1.6	9.9
83	76.0	– 003085	.581	10.7	9.4
81	284.7	–.002103	.826	8.3	9.1
85	(86.8)	–.005350	(.515)	(8.4)	10.9
86	76.9	(–.002250)	.624	4.3	8.8
87	(76.9)	–.002250	(.624)	4.5	9.2
88	14.7	–.004502	.398	6.4	9.4
89	(146.0)	(–.001764)	.855	5.1	8.3
90	218.9	–.004928	.659	.9	8.8
91	(125.5)	–.004541	.480	(10.0)	9.2
92	(125.5)	.003351	(.734)	(10.0)	9.2
93	(132.0)	(– 002494)	.720	5.6	8.1
94	(35.8)	(–.005208)	(.491)	4.9	9.1
95	(35.8)	–.005488	.436	7.9	8.9
96	(125.5)	–.004997	.621	.7	8.9
97	(125.5)	–.001911	.301	3.2	9.8
98	48.0	(–.003890)	.338	2.8	8.8
99	(63.6)	–.002517	.708	10.9	8.9
100	300.0	–.003660	(.734)	3.5	9.3
101	(35.8)	–.002146	(.491)	2.6	8.8
102	(86.8)	(–.003840)	.855	2.5	9.1
103	(133.7)	(–.004710)	.355	.9	9.3
104	210.8	(–.003261)	(.491)	3.2	9.1
105	(133.7)	(–.004710)	.831	.6	9.1
106	(43.5)	(–.002890)	.886	3.5	9.0
107	243.8	(–.002081)	(.896)	1.2	9.7
108	273.6	(–.004020)	.559	2.9	9.2
109	(130.0)	(–.004453)	(.820)	2.4	10.1
110	300.0	–.005212	(.734)	.2	9.1
111	334.0	–.001845	(.499)	.7	8.7
112	(80.4)	–.002655	.634	4.7	9.1
113	(63.6)	–.005663	.651	.6	8.6

4. Results and Discussion

For each site, the difference $I_{obs} - I_{cal}$ was calculated and was considered as a site effect index. In figure 2, a plot of the residual, $I_{obs} - I_{cal}$, versus epicentral distance, Δ, is presented. As it can be seen from this figure, there is a slight increase of $I_{obs} - I_{cal}$ with the epicentral distance. The solid line in figure 2 is the least squares' fit to the data given by:

$$I_{obs} - I_{cal} = 0.0048\Delta - 0.063 \quad (6)$$

This correlation of the residuals with distances probably suggests that some part of the anelastic attenuation was not calculated by the processing of the data of each event. Figure 3 shows a plot of the residuals $I_{obs} - I_{cal}$ versus surface wave magnitude, M_s. No correlation can be identified between the two quantities.

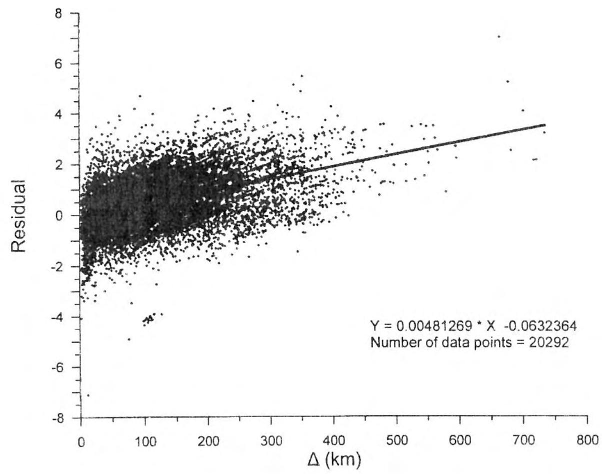

Fig. 2 – Plot of the residual ($I_{obs} - I_{cal}$) for each site versus epicentral distance, Δ.

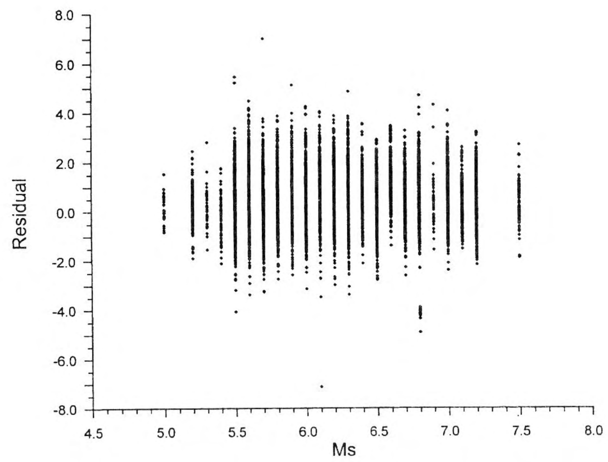

Fig. 3 – Plot of the residual ($I_{obs} - I_{cal}$) versus surface wave magnitude, M_s.

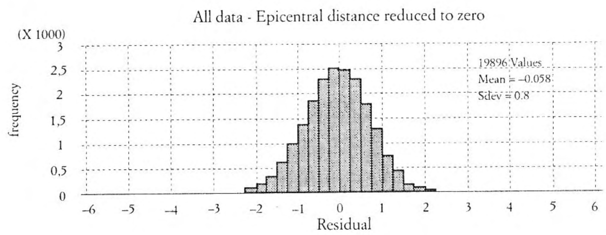

Fig. 4 – Frequency histogram of the residuals ($I_{obs} - I_{cal}$).

Thus, in order to study the spatial distribution of the residual intensities, these residuals were initially normalized to zero epicentral distance using relation (6).

For each site, an average residual and the corresponding standard deviation were calculated, and this average was recalculated excluding this time the values that were not within ±2 standard deviations. Figure 4 shows the frequency diagram of the final residuals used. As it can be seen, the residual follow a normal distribution with mean value close to zero (–0.06) and a standard deviation equal to 0.80.

In Table 3, information is given on the average residuals calculated for 546 selected sites in the area of Greece, for which at least 10 macroseismic observations were available. The name of the site is given in the first column and its geographical coordinates are given in the second and the third column. The number of the macroseismic observations that were used for each site is given in the fourth column, while the average residual is presented in the fifth column and the standard deviation in the sixth column. It is important to notice from this last column that in more than 80% of the sites the estimated standard deviation is smaller than the corresponding value for all the data shown in figure (4). This indicates that there is less variability in the intensity residual for each site, hence there is still information in figure (4) which we interpret as a site effect.

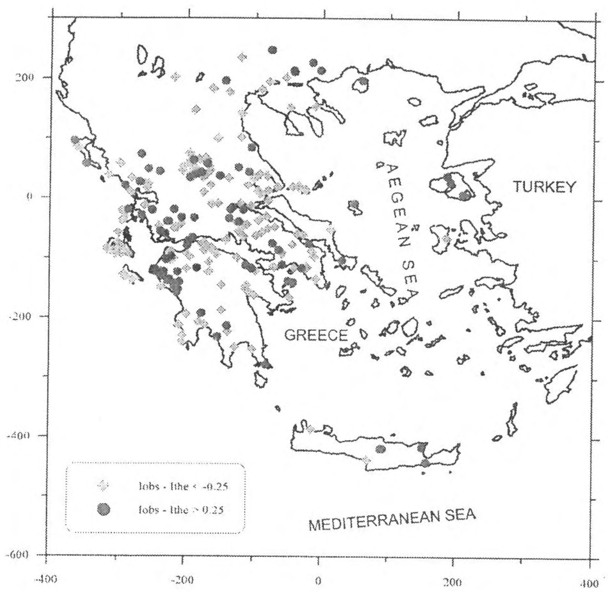

Fig. 5 – Spatial distribution of the average residuals of sites with at least 10 macroseismic observations. Positive values correspond to amplification and negative to deamplification.

Figure 5 shows the spatial distribution of the average residuals for all sites with more than 10 macroseismic observations. As it can be seen from this map, there is some tendency of clustering of positive residuals (amplification) in some areas with dimensions of the order of tenths of kilometers (e.g. in northwestern Peloponnese, Lesvos island, etc.) and of negative residuals in other areas of similar dimensions (e.g. in Cephalonia island, in Zakynthos island, etc.). There are, however, many cases where sites of positive and negative residuals are very close. For this reason, the best way to make a practical use of the calculated residuals is to take their values directly from Table 3.

Figure 6 shows the direction of the major axis of the elliptical isoseismals in the broader Aegean area. A thick solid line and solid circles are used for those earthquakes for which this direction was calculated

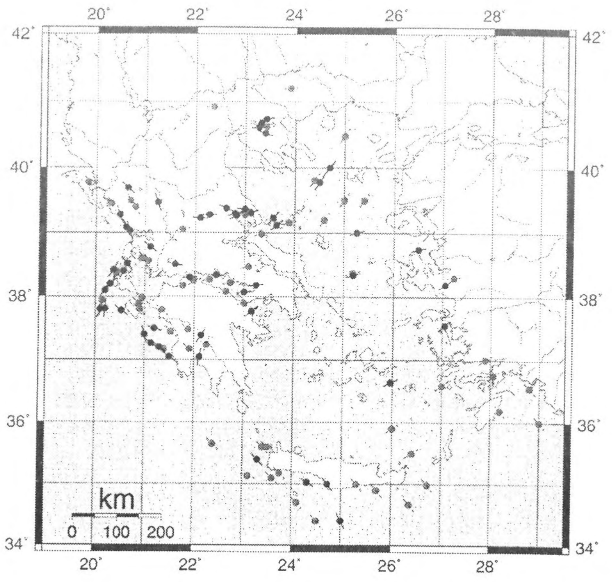

Fig. 6 – Plot of the calculated direction of the elliptical isoseismals in the broader Aegean area.

using the procedure previously described. Thin dashed lines and gray circles are used when the direction was accepted from the surrounding events. Comparison of these directions with fault plane solutions[28] suggests that the azimuth of the maximum axis of the isoseismals coincides with the fault direction, for all types of focal mechanisms. This conclusion suggests that the rupture direction plays an important role for the radiation pattern of the events of the examined area. Hence, this observation is important if we want to deduce accurate results about site effects, which will not be affected by «amplification effects» caused by the energy radiation of each earthquake.

Of course, it is possible that the systematic behaviour observed in figure (6) is occasionally the result of the specific distribution of intensity observations which only come from land areas, especially in the Ionian and Aegean sea regions. For instance, in the Ionian sea area the intensity observations locally have an azimuthal gap which exceeds 180°. However, this gap is not a problem for this area where the isoseismal directivity is clear; numerous isoseismals exhibit the same prominent isoseismal elongation along the west Greece coasts and a strong intensity attenuation towards the Greek mainland. As far as the Aegean sea is concerned, this problem is secondary due to the high island density, especially in the southern Aegean, which provide a large number of intensity observations.

5. Acknowledgments

We would like to express our gratitude to the Ordinance Survey of Greece and to the Hellenic Corporation of Local Authority and Development of Greece for offering information on the geographical coordinates of the sites used in the present paper. We would also like to thank Prof. B. Papazachos for his fruitful comments and his constant support throughout this work.

Table 3 – *Information on the name,geographic coordinates,* ϕ_N^0, λ_E^0, *number of macroseismic observations, n, average residual, RESave, and standard deviation, Sdev, for each site.*

Site Name	ϕ_N^0	λ_N^0	n	RESave	Sdev
ADENDRON	40,67	22,60	11	–0,2	0,9
AFIDNAI	38,20	23,83	10	–0,4	0,8
AFRATION	38,45	23,68	15	–0,3	0,7
AGIA	39,30	20,35	16	–0,3	1,2
AGIA	39,72	22,75	17	–0,1	0,6
AGIA ANNA	38,92	24,57	11	0,8	0,9
AGIA EIRINI	38,12	20,75	10	–0,5	0,6
AGIA MAVRA	37,87	21,30	10	–0,4	1,1
AGIA PARASKEVI	37,78	23,90	10	–0,3	0,6
AGIA PARASKEVI	39,12	21,02	22	–0,5	0,7
AGIA TRIAS	38,30	23,13	11	0,0	0,6
AGIA TRIAS	37,53	22,53	13	0,2	0,9
AGIA VARVARA	35,10	25,30	12	0,2	0,4
AGIOI ANARGYROI	39,75	22,77	14	0,7	0,5
AGIOS ANDREAS	37,30	22,33	10	–0,5	1,0
AGIOS DIMITRIOS	38,52	22,80	14	0,1	0,7
AGIOS GEORGIOS	38,18	23,55	11	–0,2	1,3
AGIOS GEORGIOS	38,15	22,22	11	–0,5	1,0
AGIOS GEORGIOS	37,75	21,45	12	0,4	0,6
AGIOS GEORGIOS	38,67	22,92	13	–0,3	1,1
AGIOS IOANNIS	37,73	23,52	10	0,7	0,8
AGIOS IOANNIS	36,48	23,08	15	0,7	1,0
AGIOS KONSTANTINOS	39,13	22,27	20	0,1	1,1
AGIOS LAVRENTIOS	39,37	23,05	12	–0,1	0,8
AGIOS LEON	37,77	20,72	11	–0,6	0,6
AGIOS LOUKAS	38,07	24,35	11	0,3	0,6
AGIOS MATTHAIOS	39,48	19,87	11	0,0	0,7
AGIOS MYRON	35,23	25,02	10	0,8	0,4
AGIOS NIKOLAOS	40,35	23,55	10	0,0	0,7
AGIOS NIKOLAOS	38,17	20,67	10	–0,9	0,6
AGIOS PETROS	38,65	20,60	17	–0,2	0,7
AGIOS VASILEIOS	37,82	22,60	14	–0,1	0,7
AGIOS VLASIOS	38,80	21,48	17	0,3	0,5
AGNANTA	39,47	21,08	15	0,0	0,6
AGNANTERON	39,48	21,85	20	–0,2	0,6
AGRIA	39,33	23,00	20	0,1	0,7
AGRINION	38,62	21,40	45	0,3	0,8
AIGEIRA	38,15	22,35	15	–0,2	0,7
AIGINA	37,75	23,43	18	0,3	0,6
AIGINION	40,50	22,53	12	–0,2	0,6
AIGION	38,25	22,07	15	–0,6	0,8
AITOLIKON	38,43	21,35	46	0,6	0,6
AKRATA	38,15	22,32	16	0,1	0,4
ALEXANDREIA	40,62	22,45	13	0,0	0,9
ALIARTOS	38,37	23,10	16	–0,2	0,7
ALISSOS	38,13	21,58	17	–0,1	0,6
ALMYROS	39,18	22,77	27	–0,2	0,7
AMALIAS	37,80	21,33	30	0,3	0,6
AMARYNTHOS	38,38	23,88	12	0,0	0,4
AMFIKLEIA	38,63	22,58	11	0,3	0,3
AMFILOCHIA	38,85	21,15	35	–0,2	0,6
AMFISSA	38,52	22,38	14	0,1	0 6
AMMOTOPOS	39,27	20,95	18	0,0	0 5
AMPELAKIA	37,95	23,53	12	–0,3	0,5
AMPELOKIPOI	37,75	20,87	11	–0,5	0,6
AMPELON	39,73	22,35	12	0,1	0,5
AMPELOUZOS	35,07	24,93	10	0,1	1,0
ANALIPSIS	38,48	21,70	19	0,0	0,8
ANATOLI	39,63	20,87	12	0,2	0,9
ANAVRA	39,18	22,08	11	–0,4	0,6
ANDRAVIDA	37,90	21,27	31	0,2	0,5
ANDRITSAINA	37,48	21,90	10	0,1	0,8
ANDROUSA	37,10	21,93	13	0,0	0,5
ANEZA	39,08	20,92	19	–0,1	0,8
ANGELOKASTRON	38,57	21,28	28	–0,1	0,6
ANO KALENTINI	39,25	21,17	11	–0,1	0,8
ANO KASTRITSION	38,27	21,83	17	–0,1	0,8
ANO KORAKIANA	39,70	19,78	16	–0,6	0,6
ANO LECHONIA	39,33	23,05	11	–0,5	0,7
ANO VIANNOS	35,05	25,42	10	0,0	0,6
ANOGEIA	36,98	22,43	11	–0,6	0,7
ANTHILI	38,85	22,47	17	0,5	0,6
ANTIRRION	38,33	21,75	12	0,5	0,9
ANTISSA	39,28	26,02	11	0,2	0,6
ANTRONION	37,80	21,72	12	–0,1	0,5
ARACHOVA	38,48	22,58	13	–0,4	0,5
ARCHAIA KORINTHOS	37,90	22,88	14	–0,4	1,0
ARCHAIA NEMEA	37,80	22,70	10	0,1	0,7
ARFARA	37,15	22,05	11	0,1	0,8
ARGALASTI	39,22	23,22	16	–0,2	0,4
ARGOS	37,63	22,72	28	–0,3	0,6
ARGOSTOLION	38,17	20,48	25	–0,3	0,7
ARNAIA	40,48	23,58	18	–0,2	0,9
ARTA	39,15	20,98	20	–0,1	0,3
ARTESIANON	39,40	21,88	28	0,2	0,6
ASINI	37,53	22,87	13	–0,4	1,1
ASOPIA	38,30	23,50	18	–0,4	0,7
ASOPOS	36,72	22,85	12	–0,5	0,8
ASPROPYRGOS	38,05	23,58	14	–0,1	0,7
ASSOS	37,93	22,82	30	0,3	0,6
ASTAKOS	38,55	21,08	27	0,1	0,7
ASTROS	37,40	22,72	19	0,1	0,6
ATALANTI	38,65	22,98	26	0,1	0,5
ATHAMANION	39,37	21,22	10	0,5	0,6
ATHIKIA	37,82	22,92	23	0,0	0,6
ATHINAI	37,98	23,72	18	–0,2	0,4
AVGEION	37,87	21,35	11	0,4	0,7
AVLONARION	38,50	24,12	19	–0,2	0,7
AVRAMION	37,03	21,93	16	0,1	0,7
BRALOS	38,72	22,47	11	0,0	0,8
CHALANDRITSA	38,10	21,78	27	–0,6	0,8
CHALKI	39,57	22,53	12	–0,2	0,9
CHALKIOPOULOI	38,97	21,40	15	0,1	0,7
CHALKIS	38,47	23,58	20	–0,5	0,6
CHANDRINOS	36,95	21,78	22	0,1	0,5
CHANIA	35,52	24,02	14	0,2	0,8
CHAROKOPEION	36,80	21,90	14	0,3	0,6
CHAVARION	37,85	21,38	15	0,2	0,4
CHAVDATA	38,20	20,38	13	–0,5	1,0
CHAVRIATA	38,18	20,38	10	–1,3	0,6
CHELIDONION	37,72	21,62	11	0,7	0,8
CHILIOMODION	37,80	22,87	12	0,0	0,6
CHIOS	38,38	26,13	11	–0,6	0,7
CHLOMOS	39,45	19,95	10	0,3	0,6
CHORA	36,90	22,27	17	0,5	1,0
CHRYSON	38,47	22,47	23	–0,1	0,6
DAFNI	37,95	23,73	16	–0,3	0,5
DAFNI	37,80	22,02	19	–0,2	0,5
DAVLEIA	38,52	22,73	14	–0,2	0,6
DERVENION	38,13	22 42	25	0,0	0,5
DESFINA	38,42	22,52	23	–0,2	0,8
DIAKOPTON	38,18	22,20	21	–0,2	0,5
DIMINION	39,35	22,90	10	–0,7	1,0
DIMITSANA	37,58	22,03	13	0,2	0,5
DISTOMON	38,42	22,67	14	–0,3	0,8
DOKIMION	38,62	21,38	28	0,5	0,6
DOMOKOS	39,12	22,30	20	–0,2	0,9
DORION	37,28	21 ,85	22	–0,1	0,7
DRAKOTRYPA	39,38	21,60	21	–0,3	0,8
DREPANON	38,32	21,85	16	–0,2	0,6
DROSIA	37,92	21,73	13	–0,4	0,7
EDESSA	40,80	22,05	14	0,0	0,8
EFKARPIA	40,87	23,77	11	–0,2	0,6
EFXEINOUPOLIS	39,18	22,72	12	–0,5	0,6
EFYRA	37,85	21,52	10	0,0	0,4
EGKLOUVI	38,73	20,63	11	–0,7	0,8
ELASSON	39,88	22,18	16	–0,5	0,7
ELATEIA	38,63	22,75	11	0,1	0,6
ELEFSIS	38,03	23,53	18	0,1	0,5
EPANOMI	40,43	22,92	11	–0,2	0,7

Table 3 – *(cont).*

Site Name	ϕ_N^0	λ_N^0	n	RESave	Sdev
EPISKOPI	40,58	22,37	12	–0,3	0,7
ERETRIA	38 38	23,78	17	0,1	0,5
EVA	37,12	21,95	15	–0,3	1,0
EVANGELISMOS	36,83	21,77	11	0,0	0,8
EVINOCHORION	38,37	21,53	17	–0,1	1,0
EVZONOI	41,10	22,55	10	–0,3	0,9
EXANTHEIA	38,75	20,62	10	–0,3	0,3
FALLANA	39,72	22,40	10	–0,1	0,9
FARKADON	39,57	22,02	10	–0,3	0,8
FARSALA	39,28	22,38	11	–0,7	1,0
FIKI	39,52	21,65	10	–0,2	0,9
FILIATAI	39,60	20,30	16	0,0	0,6
FILIATRA	37,15	21,58	23	0,0	0,7
FILIPPIAS	39,20	20,88	22	0,4	0,5
FLORINA	40,78	21,40	12	–0,3	0,7
FOURNA	39,07	21,88	18	0,0	0,8
FOURNI	35,25	25,67	10	0,5	0,4
GAITANION	37,78	20,87	10	0,0	0,3
GALATADES	40,75	22,28	11	0,5	0,8
GALAXIDION	38,37	22,37	24	–0,6	0,7
GARGALIANOI	37,07	21,63	27	–0,3	0,7
GASTOUNI	37,85	21,25	30	0,7	0,7
GASTOURION	39,55	19,90	10	–0,1	0,6
GAVALOU	38,53	21,53	33	–0,4	0,7
GLOSSA	39,17	23,60	10	–0,3	0,9
GOMFOI	39,47	21,68	12	–0,1	0,6
GONNOI	39,85	22,50	10	0,0	0,5
GOUMERON	37,75	21,62	19	0,1	1,0
GOURIA	38,47	21,27	11	0,6	0,8
GRAMMATIKON	38,20	23,95	14	–0,2	0,6
GRAMMATIKOU	38,52	21,50	22	–0,4	0,8
GRAMMENITSA	39,18	20,98	14	–0,7	0,9
GREVENA	40,08	21,42	11	0,1	0,7
GYTHEION	36,75	22,55	15	–0,3	0,6
IERAPETRA	35,02	25,73	10	0,3	0,7
IERISSOS	40,38	23,87	15	–0,4	0,6
IGOUMENITSA	39,50	20,27	13	–0,1	0,6
IOANNINA	39,67	20,85	14	0,2	0,6
IRAKLEION	35,35	25,12	21	0,1	0,7
ISTHMIA	37,92	23,00	18	0,0	0,6
ISTIAIA	38,95	23,15	16	0,2	0,4
ITEA	38,43	22,42	29	0,2	0,6
ITHAKI	38,37	20,72	27	–0,2	0,7
KAINOURGION	38,60	21,48	33	0,2	0,7
KAISARIANI	37,97	23,75	12	–0,6	0,6
KAKOVATOS	37,47	21,63	13	0,1	0,9
KALAMATA	37,03	22,10	19	–0,1	0,5
KALAMITSION	38,75	20,60	10	–0,9	0,5
KALAMPAKA	39,70	21,62	16	–0,1	0,6
KALAVRYTA	38,03	22,10	19	–0,3	0,7
KALFAS	37,90	21,60	10	0,1	1,2
KALIDONA	37,47	21,70	21	0,2	0,6
KALLIFONION	39,28	21,97	16	–0,4	0,7
KALLITHEA	40,27	22,58	10	–0,3	0,8
KAMARAI	38,30	22,00	19	–0,3	0,5
KAMARION	38,10	22,57	10	–0,5	0,5
KAMENA VOURLA	38,77	22,77	13	–0,1	0,8
KANALIA	39,40	21,80	11	–0,4	0,5
KANALION	39,07	20,70	18	–0,4	1,3
KANDILA	37,77	22,37	10	–0,2	0,7
KANDILA	38,70	20,93	11	0,6	0,6
KAPANDRITION	38,22	23,87	14	–0,2	0,8
KARATOULAS	37,73	21,53	12	–0,2	0,7
KARDAMAS	37,77	21,33	11	–0,1	0,7
KARDAMYLA	38,53	26,08	11	–0,1	0,5
KARDITSA	39,37	21,92	25	0,4	0,5
KARDITSOMAGOULA	39,38	21,92	23	0,0	0,6
KAROUSADES	39,78	19,73	12	0,3	0,7
KARPERI	41,13	23,30	10	0,2	0,7
KARPOCHORION	39,33	22,02	16	–0,5	0,7
KARVOUNARION	39,38	20,48	10	0,0	1,0

Table 3 – *(cont).*

Site Name	ϕ_N^0	λ_N^0	n	RESave	Sdev
KARYA	38,75	20,65	19	–0,1	0,6
KARYSTOS	38,02	24,42	13	0,1	0,3
KASTELLION	38,68	22,42	14	0,3	0,7
KASTOREION	37,17	22,30	11	–0,1	0,7
KASTORIA	40,52	21,27	10	–0,2	0,6
KATAKOLON	37,63	21,32	16	–0,5	0,7
KATARRAKTIS	39,45	21,10	11	0,1	1,0
KATERINI	40,27	22,50	17	–0,1	0,7
KATO ACHAIA	38,15	21,55	15	–0,1	0,5
KATO KORAKIANA	39,68	19,82	12	–0,3	0,5
KATO LECHONIA	39,33	23,03	15	–0,2	1,1
KATO TITHOREA	38,60	22,72	12	–0,3	0,7
KATOCHI	38,40	21,25	18	0,1	0,6
KATOUNA	38,78	20,70	10	0,3	0,5
KATOUNA	38,78	21,12	39	0,3	0,6
KATSIKAS	39,62	20,88	19	0,4	0,5
KEFALOVRYSON	39,58	21,68	12	0,2	0,4
KERAMION	39,22	26,22	13	0,8	0,7
KERATSINION	37 95	23,62	11	0,0	0,5
KERION	37,67	20,80	10	–0,2	0,6
KERKINI	41,22	23,08	10	0,5	1,0
KERKYRA	39,62	19,92	20	–0,1	0,6
KERTEZI	37,98	21,98	25	0,1	0,7
KIATON	38,00	22,75	10	0,2	0,5
KIFISIA	38,07	23,80	12	0,1	0,5
KLEITOR	37,88	22,10	11	–0,7	0,4
KLEITORIA	37,88	22,12	10	0,0	0,9
KOLLINAI	37,28	22,35	15	0,1	0,9
KOMOTINI	41,12	25,40	12	0,0	0,6
KORFOVOUNION	39,25	20,98	17	–0,1	0,7
KORINOS	40,32	22,58	14	0,0	0,5
KORINTHOS	37,93	22,92	22	–0,1	0,8
KORONI	37,23	21,75	17	–0,3	0,6
KOROPION	37,90	23,87	16	0,2	0,7
KORYFASION	37,00	21,67	11	–0,2	0,7
KORYFI	40,60	22,50	12	–0,1	0,8
KORYNI	38,25	22,98	15	–0,2	0,7
KOS	36,90	27,30	13	–0,1	1,2
KOSKINAS	39,50	22,02	15	0,3	0,6
KOUNINA	38,20	22,02	14	–0,4	0,7
KOUTSOPODION	37,68	22,72	11	–0,4	0,7
KOZANI	40,30	21,78	13	–0,3	0,5
KRANEA	39,25	20,73	12	–0,4	1,0
KRANIDION	37,38	23,15	13	0,0	0,8
KRESTENA	37,60	21,62	23	0,1	0,9
KROUSON	35,23	24,98	10	0,8	0,5
KRYONERION	37,97	22,63	12	0,0	0,6
KYLLINI	37,93	21,13	15	0,2	1,0
KYMI	38,63	24,10	21	0,2	0,8
KYPARISSIA	37,25	21,67	31	–0,2	0,8
KYRIAKION	38,35	22,78	12	–0,2	0,3
LADIKOU	38,90	22,22	13	–0,4	0,7
LAFKOS	39,17	23,23	12	–0,6	0,8
LAGKADA	38,48	26,12	10	0,0	0,6
LAGKADAS	40,75	23,07	17	–0,3	0,8
LAGKADIA	37,68	22,02	15	0,1	0,6
LAKKOPETRA	38,17	21,45	20	–0,5	0,8
LAMIA	38,90	22,43	25	0,0	0,7
LANTHION	37,70	21,52	11	0,3	0,8
LARISA	39,63	22,42	34	0,2	0,6
LECHAINA	37,93	21,27	25	0,1	0,5
LECHAION	37,93	22,88	20	0,2	0,7
LECHOURION	37,95	21,92	14	0,0	0,8
LEFKAS	38,90	22,00	10	0,0	0,8
LEFKAS	38,82	20,70	42	–0,1	0,7
LEFKIMMI	39,42	20,07	15	0,3	0,8
LEFKTRA	38,25	23,18	12	0,0	0,6
LEIANOKLADION	38,92	22,30	20	0,0	0,7
LEONIDION	37,17	22,85	16	–0,1	0,8
LEONTARION	39,18	22,12	12	–0,2	0,8
LEPENOU	38,70	21,28	13	–0,2	0,6

Table 3 – (cont).

Site Name	ϕ_N^0	λ_N^0	n	RESave	Sdev
LEPREON	37,43	21,72	12	0,1	1,0
LEVADEIA	38,43	22,87	18	–0,3	0,9
LEVIDION	37,68	22,30	12	–0,8	0,6
LIMNI	38,77	23,32	18	0,1	0,4
LITHAKIA	37,72	20,83	14	–0,2	0,5
LIVANATAI	38,72	23,05	15	–0,3	0,7
LIVARTZION	37,93	21,90	10	0,5	1,0
LIXOURION	38,20	20,43	24	–0,2	0,8
LOFOS	40,23	22,38	10	–0,1	0,7
LONGOS	38,30	22,02	11	–0,4	0,6
LOUROS	39,17	20,75	14	0,2	0,8
LOUSIKA	38,10	21,60	15	0,2	0,7
LOUTRAKION	37,98	22,97	15	0,1	0,4
LYGOURION	37,62	23,03	15	–0,2	0,5
MAGOULA	39,45	21,80	12	–0,3	0,8
MAGOULA	37,07	22,40	13	–0,2	0,9
MAKRAKOMI	38,95	22,10	12	–0,1	0,7
MAKRIOTIKA	38,30	20,55	10	–0,9	0,7
MAKRISIA	37,60	21,60	25	0,5	0,6
MALEME	35,52	23,85	10	–0,3	0,5
MALESINA	38,62	23,23	11	0,0	0,9
MANOLAS	38,05	21,35	22	0,0	0,8
MARATHON	38,12	23,95	20	0,2	0,7
MARIAI	37,82	20,67	12	–0,4	0,3
MARMARION	38,05	24,32	11	–0,1	0,6
MARTINON	38,57	23,20	14	–0,3	0,7
MATARAGKA	39,40	22,07	20	–0,6	0,9
MATARAGKA	38,52	21,47	30	0,2	0,6
MAZARAKION	37,87	21,58	10	0,3	0,7
MEGALA KALYVIA	39,50	21,78	12	–0,2	0,9
MEGALI PANAGIA	40,43	23,68	12	0,0	0,5
MEGALOCHORION	39,55	21,83	11	0,2	0,6
MEGALOPOLIS	37,42	22,12	25	0,2	0,5
MEGARA	38,00	23,33	21	0,3	0,8
MELAMPES	35,12	24,65	13	–0,2	0,8
MESAGROS	39,03	26,43	10	1,1	1,0
MESENIKOLAS	39,33	21,75	15	–0,3	1,0
MESOLONGION	38,37	21,42	20	0,2	0,5
MESSINI	37,18	21,92	21	0,3	0,6
METHONI	36,82	21,70	10	–0,7	0,9
METOCHION	38,20	22,17	27	–0,2	1,2
METSOVON	39,77	21,18	11	–0,1	0,5
MICHALITSION	39,03	20,73	16	–0,5	0,9
MIKROMANI	37,08	22,02	11	0,2	1,0
MINTILOGLION	38,18	21,70	20	0,2	0,7
MITROPOLIS	39,33	21,83	18	0,4	0,7
MOLOS	38,82	22,65	28	0,5	0,6
MONASTIRAKION	38,85	20,95	16	–0,1	0,8
MOSCHATON	37,95	23,67	12	0,5	0,7
MOSCHOCHORION	38,82	22,43	12	0,4	0,8
MOUSTHENI	40,85	24,10	13	–0,2	0,9
MOUZAKION	37,78	21,55	10	0,0	0,6
MOUZAKION	39,43	21,67	11	–0,2	0,5
MOUZAKION	37,73	20,82	11	–0,3	0,4
MYRA	39,45	22,55	10	0,4	0,5
MYRINA	39,87	25,07	10	–0,2	0,5
MYRSINI	39,13	20,63	13	0,3	0,8
MYRTEA	38,58	21,62	12	–0,3	0,6
MYRTOS	38,07	21,50	11	–0,4	0,5
MYSTRAS	37,07	22,37	14	–0,2	0,7
MYTIKAS	38,43	23,65	12	0,0	0,5
MYTIKAS	38,68	21,62	15	0,5	1,1
MYTILINI	39,10	26,57	10	–0,2	0,9
NAFPAKTOS	38,38	21,82	39	0,3	0,9
NAFPLION	37,57	22,80	24	–0,3	0,7
NAOUSA	40,63	22,07	14	–0,4	0,7
NEA ALIKARNASSOS	35,33	25,15	11	0,2	0,4
NEA ANCHIALOS	39,28	22,82	12	–0,3	0,6
NEA AVORANI	38,60	21,43	22	0,1	0,6
NEA FILADELFEIA	38,03	23,73	17	–0,2	0,8
NEA IONIA	39,37	22,92	13	–0,4	0,8

Table 3 – (cont).

Site Name	ϕ_N^0	λ_N^0	n	RESave	Sdev
NEA KARYA	40,90	24,72	10	0,0	0,3
NEA KIOS	37,58	22,73	11	0,0	0,6
NEA MANOLAS	38,05	21,38	13	0,4	1,0
NEA MOUDANIA	40,23	23,28	17	–0,2	0,7
NEA PALATIA	38,32	23,78	15	0,3	0,4
NEA PERAMOS	40,83	24,30	10	0,2	0,6
NEA PERAMOS	38,00	23,40	11	–0,2	0,5
NEA SELEFKEIA	39,52	20,25	11	0,2	1,0
NEA STYRA	38,18	24,20	11	0,1	0,4
NEA TRIGLIA	40,30	23,20	10	0,2	0,4
NEA ZICHNI	41,03	23,82	11	0,6	0,7
NEAPOLIS	36,50	23,07	10	0,1	0,6
NEAPOLIS	35,25	25,60	10	–0,1	0,8
NEAPOLIS	40,65	22,93	11	0,0	0,8
NENITA	38,23	26,10	14	0,0	0,5
NEOCHORION	39,28	21,73	10	0,5	0,8
NEOCHORION	38,30	26,10	11	–0,2	0,5
NEOCHORION	39,60	21,98	12	–0,3	0,8
NEOCHORION	37,90	21,20	13	0,4	0,6
NEOCHORION	38,68	21,83	26	0,3	0,8
NEOCHOROUDA	40,73	22,87	11	–0,2	0,8
NEON MONASTIRION	39,23	22,27	15	–0,2	0,7
NEON PSYCHIKON	38,00	23,78	12	0,2	0,4
NEOS PYRGOS	38,93	23,08	10	0,0	0,5
NEOS SKOPOS	41,02	23,60	13	–0,2	0,6
NIGRITA	40,90	23,50	10	0,3	0,7
NIKAIA	39,57	22,47	10	–0,1	0,5
OCHTHONIA	38,53	24,15	14	–0,3	0,3
OICHALIA	37,25	22,00	16	0,6	1,0
ORCHOMENOS	38,48	22,97	24	–0,3	0,6
OREOI	38,95	23,08	13	–0,7	0,6
OXYLITHOS	38,58	24,10	15	–0,1	0,5
PAIANIA	37,95	23,85	11	–0,2	0,4
PAIANIA	37,95	23,85	11	–0,2	0,4
PALAIA EPIDAVROS	37,63	23,15	12	0,2	0,6
PALAIOMANINA	38,55	21,23	27	–0,3	0,7
PALAION FALIRON	37,93	23,70	11	0,0	0,5
PALAIOPYRGOS	39,60	21,80	10	–0,1	0,8
PALAIROS	38,78	20,88	33	–0,2	0,7
PALAMAS	39,47	22,05	22	–0,4	0,8
PALIAMPELA	38,87	21,33	19	–0,1	0,6
PANAGIA	38,48	22,60	11	–0,1	0,7
PANAITOLION	38,58	21,43	22	–0,2	0,6
PANARITION	37,98	22,53	19	0,1	0,6
PANTOKRATOR	37,73	20,82	19	0,1	0,9
PAPPADATAI	39,30	20,78	16	0,0	0,7
PAPPADATAI	38,52	21,45	22	–0 1	0,7
PAPPADATOS	38,70	21,17	23	0,0	0,7
PARAKALAMOS	39,85	20,57	13	0,0	0,9
PARAMYTHIA	39,47	20,52	12	–0,4	0,6
PARAVOLA	38,62	21,53	24	0,2	0,7
PARGA	39,28	20,40	18	–0,1	0,9
PATIOPOULON	39,08	21,25	28	–0,2	0,9
PATMOS	37,30	26,53	11	0,0	1,4
PATRAI	38,27	21,73	33	0,3	0,7
PAVLOS	38,53	23,08	11	–0,5	0,6
PELASGIA	38,95	22,83	13	–0,2	0,6
PELOPION	37,68	21,58	30	0,1	0,5
PERAMA	39,70	20,83	10	–0,2	0,9
PERIGIALION	37,93	22,83	27	–0,3	0,8
PERISTASIS	40,27	22,53	11	–0,1	0,6
PETAS	39,17	21,03	16	–0,4	0,5
PETRA	39,32	26,17	10	0,4	0,6
PETROTON	39,58	21,95	12	0,1	0,9
PIGAI	39,28	21,40	11	0,0	0,9
PIGI	39,50	21,70	18	–0,3	0,6
PLATAIAI	38,22	23,27	14	0,4	0,6
PLATANOS	39,13	22,77	13	–0,2	0,8
PLATANOS	37,67	21,62	14	–0,2	1,0
PLATANOS	38,60	21,32	24	0,1	0,8
PLATANOUSSA	39,40	21,02	10	0,4	0,6

Table 3 – (*cont*).

Site Name	ϕ_N^0	λ_N^0	n	RESave	Sdev
PLATANOVRYSI	38,13	21,73	11	–0,4	0,7
PLATY	37,13	22,00	13	–0,1	0,7
PLATYKAMPOS	39,62	22,53	13	–0,1	0,6
POLYDROSOS	38,63	22,53	21	–0,7	0,8
POLYGYROS	40,37	23,43	15	–0,5	0,7
POROS	37,50	23,45	13	–0 5	0,8
POULATA	38,23	20,60	10	–0,7	0,4
PREVEZA	38,95	20,75	25	0,1	0,6
PROVATAS	41,07	23,38	10	0,0	0,7
PSATHOPYRGOS	38,32	21,87	11	–0,1	0,9
PTELEOS	39,05	22,95	10	–0,4	0,7
PTOLEMAIS	40,52	21,67	16	0,2	0,3
PYLI	39,45	21,62	14	–0,7	0,7
PYLOS	36,92	21,70	17	–0,4	0,5
PYRGETOS	39,92	22,58	10	–0,3	0,7
PYRGOS	37,67	21,43	13	0,2	0,8
RACHAI	38,88	22,78	13	–0,6	0,8
RAPTOPOULON	39,15	21,47	16	0,1	0,6
RENTINA	39,07	21,97	14	–0,3	0,8
RETHYMNON	35,37	24,48	13	–0,2	0,6
RIOLOS	38,05	21,45	16	–0,4	0,8
RIZOMA	39,65	21,72	14	–0,3	0,7
RIZOMYLOS	39,43	22,75	13	0,0	0,7
RIZOVOUNION	39,27	20,80	22	0,1	0,8
RODODAFNI	38,25	22,03	19	–0,5	0,8
RODOLIVOS	40,92	23,97	11	0,3	0,9
ROVIAI	38,82	23,22	11	0,2	0,5
SAGAIIKA	38,10	21,47	26	0,4	0,7
SALMONI	37,65	21,53	20	0,5	0,8
SAMI	38,25	20,65	17	0,1	0,6
SAMIKON	37,57	21,58	11	0,4	0,6
SAVALIA	37,82	21,30	14	0,7	0,8
SERRAI	41,08	23,55	11	0,0	0,6
SIKYON	37,98	22,72	18	0,3	0,8
SIMOPOULON	37,85	21,57	13	0,2	0,6
SITEIA	35,20	26,10	11	–0,1	0,8
SKANDALON	39,37	20,53	11	0,0	0,8
SKIADAS	37,88	21,68	13	0,1	0,9
SKIATHOS	39,17	23,48	15	–0,6	0,5
SKOPELOS	39,12	23,72	19	–0,8	0,7
SKOURA	37,02	22,48	11	0,0	0,5
SKYROS	38,90	24,57	19	–0,1	0,5
SOCHOS	40,82	23,35	15	–0,3	0,8
SOFADES	39,33	22,10	28	0,1	0,7
SOFIKON	37,80	23,05	28	0,2	0,7
SOURPI	39,10	22,90	15	–0,9	0,7
SPARTI	37,07	22,43	10	0,2	0,4
SPERCHEIAS	38,90	22,12	19	–0,4	0.9
STADION	37,45	22,42	15	0,0	0,9
STAMATA	38,12	23,87	10	–0,5	0,9
STAMNA	38,52	21,27	33	–0,1	0,7
STAVROS	40,48	23,17	12	–0,1	0,9
STAVROS	39,32	22,23	13	0,5	0,5
STEFANOVIKEION	39,47	22,73	15	–0,1	1,0
STIMAGKA	37,90	22,70	12	–0,2	0,7
STRATOS	38,67	21,32	13	0,1	0,7
STREFION	37,67	21,55	19	0,8	0,5
STRYMONIKON	41,03	23,30	10	–0,1	0,7
STYLIS	38,92	22,60	24	–0,3	0,7
SVORONATA	38,12	20,52	20	–0,8	0,4
SYKOURION	39,75	22,58	10	–0,1	0,5

Table 3 – (*cont*).

Site Name	ϕ_N^0	λ_N^0	n	RESave	Sdev
SYVOTA	39,40	20,25	10	–0,1	0,7
SYVROS	38,67	20,65	10	–0,5	0,7
TAXIARCHAI	39,57	21,88	11	–0,3	1,1
TEMENI	38,23	22,12	15	0,0	0,8
TERPNI	40,92	23,48	10	0,4	0,8
THASOS	40,77	24,70	10	0,3	0,6
THESPIAI	38,30	23,13	11	0,0	0,9
THESPROTIKON	39,25	20,77	17	0,1	1,0
THESSALONIKI	40,63	22,93	12	–0,3	0,5
THIRA	36,42	25,43	12	0,0	1,1
THISVI	38,25	22,97	10	–0,1	0,7
THIVAI	38,32	23,32	23	0,1	0,8
THOURIA	37,08	22,05	15	–0,4	0,8
THYRION	38,85	20,98	22	–0,3	0,9
TIRNAVOS	39,75	22,28	21	0,1	0,7
TITHOREA	38,58	22,67	10	–0,5	1,1
TOULIATA	38,43	20,55	10	–1,2	0,8
TRIANDRIA	40,62	22,97	11	–0 1	0,9
TRIKALA	39,55	21,78	22	0,4	0,6
TRIKERION	39,10	23,07	20	–0,4	0,6
TRIPOLIS	37,50	22,37	30	–0,1	0,7
TROPAIA	37,73	21,95	10	–0,1	0,5
TRYFOS	38,82	21,07	17	0,2	0,5
TYMPAKION	35,07	24,77	10	–0,3	0,5
VAGIA	38,32	23,17	12	0,5	0,6
VALIMITIKA	38,23	22,13	11	–0,5	0,8
VAMOS	35,40	24,20	11	–0,1	0,5
VAMVAKOU	39,33	22,42	17	0,1	0,5
VARTHOLOMION	37,85	21,20	22	0,2	0,6
VASILIKA	40,48	23,13	17	0,1	0,5
VASILIKI	38,62	20,62	10	–0,3	0,6
VATOLAKKOS	35,45	23,88	11	0,0	0,7
VELESTINON	39,38	22,73	11	0,6	0,5
VELON	37,98	22,75	21	0,0	0,7
VELVENTOS	40,25	22,07	10	0,1	0,4
VEROIA	40,52	22,20	17	–0,1	0,8
VILIA	38,17	23,33	12	–0,5	0,4
VLACHATA	38,12	20,62	14	–0,3	0,8
VOLIMAI	37,87	20,65	18	–0,2	0,6
VOLOS	39,37	22,97	22	0,0	0,7
VONITSA	38,92	20,88	26	0,2	0,7
VOULIAGMENI	37,97	23,20	14	–0,4	1,0
VOUNARGON	37,73	21,42	22	0,3	0,6
VRACHATION	37,95	22,80	12	0,3	0,4
VRACHNAIIKA	38,10	21,48	30	0,1	0,6
VRONTADOS	38,40	26,13	10	–0,2	0,5
VYRONEIA	41,27	23,25	10	0,0	0,8
VYTINA	37,67	22,18	22	–0,2	0,5
XYLOKASTRON	38,07	22,63	26	0,1	0,7
YDRA	37,35	23,47	12	–0,2	0,8
YMITTOS	37,95	23,75	11	–0,2	0,5
YPATI	38,87	22,23	14	–0,1	0,7
ZACHARO	37,48	21,65	29	0,0	0,6
ZAGKLIVERION	40,57	23,28	12	–0,2	0,7
ZAGORA	39,43	23,08	15	–0,2	0,5
ZAKYNTHOS	37,78	20,88	18	–0,2	0,6
ZARKOS	39,62	22,12	13	–0,2	0,7
ZELION	38,65	22,85	14	–0,1	0,6
ZEVGOLATEION	37,25	21,97	12	0,2	0,5
ZIRIA	38,30	21,97	17	–0,4	0,8
ZOGRAFOS	37,97	23,77	10	0,1	0,4

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