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Sunshine duration hours over the Greek region

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With 11 Figures

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Summary

In this study, the temporal and spatial distribution of bright sunshine hours and relative sunshine duration over Greece are presented. The datasets used for this study were obtained from the archives of the Hellenic National Meteorological Service (HNMS). Furthermore, mean annual and seasonal duration of bright sunshine has been estimated from empirical formulae, which depend on the following parameters:

(i) percentage of land cover around each station (radius of 20 km),
(ii) distance of each station from the nearest coast,
(iii) height above sea level for each station location,
(iv) latitude of each station,
(v) longitude of each station.

Differences between measured and estimated bright sunshine hours are accounted for. In general a good relationship exists between estimated and observed sunshine values. The annual march of sunshine is simple with a maximum in July and a minimum in January or December. The spatial distribution of the annual and seasonal bright sunshine duration shows minimum values in the interior mountain areas of the Greek region (Western Macedonia, Epirus, Central Greece), increasing gradually towards the coasts of the Ionian and Aegean seas as well as from north to south. The highest sunshine values occur at the southeastern islands of the Aegean Sea and above the southern coasts of Crete, followed by Attica (Athens area) and the surrounding coastal areas, the islands of the eastern Aegean Sea and the southwestern coastal and island parts of the Ionian Sea.

1. Introduction

The Greek region (peninsula and islands of northeastern Mediterranean), situated in southeast Europe, includes the southern part of the Balkans and encompasses the Ionian Sea, the land areas of the Greek Peninsula and the Aegean Sea to Crete. From one end to the other, the region extends over $\delta\varphi = 8°$ of latitude and $\delta\lambda = 7°$ of longitude, approximately (Fig. 1).

The extent of the region, both in meridional and zonal direction, does not preclude a uniform climate, although it belongs mainly to the Mediterranean climate zone. From north to south and from west to east the region is not a geographical and climatological entity. It is divided into three sections (west, east and islands). The most significant topographical feature affecting the regional climate are the Pindus Mountains located along the peninsula and running from NW to SW parallel to the coast. They divide the peninsula into a western and a eastern climate section. The Greek seas areas are dotted by numerous islands, which further complicate the area's topography. Thus, another climate entity consists of the islands and the coastal areas of the Aegean Sea and the island of Crete. The climate here is more temperate owing to the sea. Such a distinction processes reasonably discrete terrestrial and

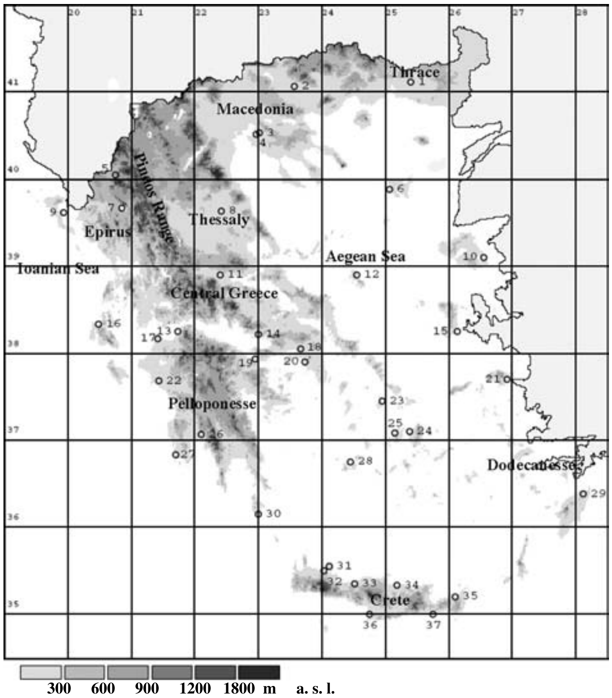

Fig. 1. Topography and location of the used climatic stations

atmospheric characteristics and relationships. The Greek region, the study area, includes subareas with different physicogeographical and climate characteristics. The whole area is classified according to Köppen's classification, mainly in the Mediterrannean climate type Csa and secondary, in the adjacent types Csb, Cfa and Cfb. Consequently, the Greek territory and its islands are considered as suitable region for studying the duration of bright sunshine hours, because of its highly variable physicogeography, namely of its large north to south extent, the complex topography, the coasts, the variability and the extent of the Ionian and the Aegean islands (Fig. 1).

Sunshine is direct radiation emitted from the disc of the sun as opposed to the shading of a location by clouds or by obstructions, it is an important climatological factor and permits the estimation of solar radiation at prime proximity. Solar irradiation intensity is measured only at few sites in the Greek region, therefore, estimations of global irradiation is based on sunshine duration data, which are widely available for Greece. The relation between global solar irradiation and sunshine duration was first demonstrated by Ångström (1924, 1956) using a simple linear model. A critical interpretation of Angström's equation have presented by Yeboah-Amankwah and Agyeman (1990) and Gueymard et al. (1995). Many studies were published concerning the effectiveness of irradiation estimates by means of statistical methods. The statistics are based either on simple linear and/or on modified quadratic and linear-logarithmic models (Prescott, 1940; Rietveld, 1978; Gopinathan, 1988; Lewis, 1989; Akinoglou and Ecevit, 1990; Wahab, 1993; Hinrichsen, 1994; Sahin and Sen, 1998; Sen, 2001). For instance, Iqbal (1979) appended a quadratic term to Prescott's formula, Gopinathan (1988) proposed a formula which relates latitude and elevation to empirical coefficients of the Ångström formula. Some other similar articles have been recently published for techniques of irradiance estimations using bright sunshine hours including Hussain et al. (1999), Singh (1996), Ampratwum and Dorvlo (1999).

Knowledge of the duration of bright sunshine at earths surface is of major importance not only from the climatological point of view but also for agrometeorological or biological purposes, engineering, architecture of the heat gains of buildings as well as for other applied environmental science studies. This is mostly important nowadays due to the widespread environmental degradation and crisis resulting from the depletion of fossil fuels, as well as the forecast increase in energy demand and the necessity to develop the exploitation of renewable energy resources.

The Greek region and the surrounding Mediterranean areas enjoy high values of bright sunshine hours, especially during the warm period of the year. This is mainly due to both, dynamical and physicogeographical factors which influence the weather and climate of the northeastern parts of the Mediterranean basin (Greek region included) during the different seasons of the year (Eginitis, 1907–1908; Mariolopoulos, 1938; Karapiperis, 1963; Met. Office, HMSO, 1962; Reiter, 1975).

Studies relating to sunshine duration in the Greek region have been carried out in the past by some investigators (e.g. Livathinos (1926), Mariolopoulos and Livathinos (1938), Van der Stok (1942) and Biel (1944)). These studies based on sunshine values that has been estimated from observed cloudiness (mean values of the

08.00, 14.00, 20.00 hours of observation) in accordance to the empirical relationship (1),

$$\nu = 8\left(1 - \frac{\eta}{\mathrm{H}}\right) \tag{1}$$

where, ν is the average daily cloudiness (in octas), η are the observed average daily sunshine hours and H are the theoretical possible daily sunshine hours. The reason for this treatment was the fact that there were no available data based on records of the duration of the bright sunshine measured by a Campbell-Stokes type of sunshine recorder (with the exception of the National Observatory of Athens station).

Since the beginning of the 1960's, studies of sunshine duration were facilitated by the availability of many stations providing complete, regular and reliable measurements by Campbell-Stokes recorder of daily sunshine hours for more than 13 years. As a result mean sunshine duration in Greece has been studied by some investigators, such as Livadas et al. (1972, 1975), Livadas and Karakostas (1975), Pennas (1976) or over the Greek peninsula by Karapiperis et al. (1974), Katsoulis and Papachristopoulos (1978), Katsoulis and Kanteres (1979), Macris (1976), Katsoulis and Leontaris (1981), Katsoulis and Kambezidis (1987).

Table 1. Geographical coordinates and elevation of the used stations

Station	Station no.	Latitude N (φ)	Rel. latitude (N to S)	Longitude E (λ)	Rel. longitude (E to W)	Elevation (m)
Komotini	1	41.07	53	25.24	384	30
Serres	2	41.04	56	23.34	274	32
Sedes	3	40.32	88	23.01	241	52
Mikra	4	40.31	89	22.58	238	4
Konitsa	5	40.03	117	20.45	105	542
Limnos	6	39.53	127	25.04	364	13
Ioannina	7	39.40	140	20.51	111	483
Larisa	8	39.38	142	22.25	205	73
Kerkyra	9	39.37	143	19.55	56	2
Mytilini	10	39.06	174	24.03	453	2
Lamia	11	38.54	186	22.24	204	144
Skyros	12	38.54	186	24.33	333	4
Patra	13	38.15	225	21.44	164	1
Aliartos	14	38.23	227	23.06	240	110
Chios	15	38.20	220	26.08	428	3
Argostolion	16	38.11	229	20.29	89	2
Araxos	17	38.10	230	21.25	145	14
N. Philadelphia	18	38.03	237	23.40	280	136
Korinthos	19	37.56	244	22.57	237	4
Helliniko	20	37.54	246	23.44	284	10
Samos	21	37.42	258	26.55	475	48
Pyrgos	22	37.41	259	21.26	146	12
Syros	23	37.27	273	24.57	357	10
Naxos	24	37.06	294	25.23	383	9
Paros	25	37.05	295	25.09	369	1
Kalamata	26	37.04	296	22.06	186	6
Methoni	27	36.50	310	21.42	162	33
Milos	28	36.43	315	24.27	327	182
Rodos	29	36.23	337	28.07	547	35
Kythira	30	36.09	351	23.00	240	167
Souda	31	35.33	387	24.07	307	139
Chania	32	35.30	390	24.02	302	62
Rethymnon	33	35.21	399	24.31	331	7
Heraklio	34	35.20	400	25.11	371	38
Sitia	35	35.12	408	26.06	426	25
Tymbakion	36	35.00	420	24.45	345	6
Ierapetra	37	35.00	420	25.45	405	16

In the present study an attempt was made to relate duration of bright sunshine in an objective way applying a bioclimate-radiation model (Matzarakis et al., 2000) and is based on guidelines of the Germany Engineering Society (VDI, 1994, 1998). This study is an improvement compared to previous works because a) it enables to examine extended time series and covers more recording sites and b) a reliable and sophisticated statistical model has been utilized.

2. Sunshine duration data

In a previous paper (Karapiperis et al., 1974) the variation and distribution of sunshine duration over the Greek region was analysed subjectively and discussed. The record was examined beginning in the 1960, because, as mentioned, at that time a Campbell-Stokes sunshine recorder network was developed by the Hellenic National Meteorological Service (HNMS). The data were based on records from 27 stations for the period 1960–1973.

In this paper, sunshine records from 37 stations in Greece were analyzed with respect to seasonal and annual variation and the geographical distribution of sunshine duration. The data are also based on records maintained by the HNMS and refer to a network of sunshine recording stations (Table 1) with their geographical

Table 2. Mean sunshine duration values (months, year, amplitude) for the stations of HNMS (in hours)

Station	J	F	M	A	M	J	J	A	S	O	N	D	Year	Amplitude
Komotini	119.6	123.7	138.1	184.9	250.3	280.3	309.3	290.8	249.4	172.0	122.8	115.6	2356.8	193.7
Serres	98.0	112.1	150.4	195.2	262.3	284.0	307.3	303.6	241.9	166.0	124.0	114.1	2358.9	209.3
Sedes	105.9	120.6	144.0	202.1	262.7	276.0	343.5	308.0	241.9	172.1	114.1	89.4	2380.3	254.1
Mikra	88.5	91.5	146.8	203.4	269.1	280.1	308.9	271.3	221.8	162.5	118.4	105.0	2267.3	220.4
Konitsa	121.5	111.8	156.4	159.1	244.1	255.9	276.5	291.0	225.7	167.3	132.5	126.5	2268.3	179.2
Limnos	81.7	110.3	161.3	221.0	294.1	324.0	362.8	337.5	271.3	196.4	127.0	94.5	2581.9	281.1
Ioannina	95.6	100.7	141.6	179.5	246.1	266.0	316.0	295.3	227.9	179.4	115.1	87.0	2250.2	229.0
Larisa	85.1	104.8	151.3	217.2	277.4	292.2	326.0	320.0	243.6	178.0	142.1	91.3	2429.0	240.9
Kerkyra	122.4	121.9	165.5	215.1	277.7	327.2	372.8	339.8	258.9	197.7	134.0	111.8	2644.8	261.0
Mytilini	106.3	121.1	159.1	211.8	305.9	339.2	381.5	354.6	292.0	205.3	144.0	113.2	2734.0	275.2
Lamia	102.6	90.4	163.5	209.9	280.2	316.7	333.8	320.0	248.1	177.1	148.0	126.8	2517.1	243.4
Skyros	75.2	96.2	133.4	212.3	301.3	332.3	362.7	340.1	267.4	181.1	127.5	93.4	2522.9	287.5
Patra	110.1	117.2	183.3	185.0	267.9	310.7	319.9	303.5	257.2	185.8	128.7	123.2	2492.5	209.8
Aliartos	84.5	109.2	148.9	209.1	279.5	305.4	351.1	324.9	244.5	168.8	138.2	87.8	2451.9	266.6
Chios	109.1	121.7	175.4	225.5	319.1	357.0	391.2	367.4	298.1	222.2	152.3	119.3	2858.3	282.1
Argostolion	150.4	137.0	163.5	208.6	309.9	334.3	366.5	343.7	272.7	194.6	148.5	119.1	2748.8	247.4
Araxos	131.3	132.5	183.9	224.9	285.1	299.5	340.7	337.5	274.2	206.3	154.5	119.6	2690.0	221.1
N. philadelphia	113.1	128.0	177.9	233.3	298.6	330.4	370.1	395.2	282.5	203.9	152.7	120.6	2806.3	282.1
Korinthos	107.7	112.6	173.1	211.4	287.7	328.8	340.6	335.6	265.3	194.5	162.8	129.3	2649.4	232.9
Helliniko	123.4	136.8	177.6	227.3	297.0	330.9	370.2	347.8	276.9	204.9	159.6	125.5	2777.9	246.8
Samos	129.3	139.2	187.9	224.6	299.3	348.7	377.6	356.3	300.5	230.6	168.4	122.4	2884.8	255.2
Pyrgos	152.7	133.2	187.2	211.3	312.1	337.8	364.4	348.2	284.8	206.4	175.4	146.2	2859.7	231.2
Syros	110.6	142.0	175.4	248.8	321.6	342.0	387.3	361.5	289.7	230.7	157.3	127.8	2894.7	276.7
Naxos	102.3	117.2	166.7	214.9	283.7	314.0	338.2	325.3	276.6	206.8	158.3	118.5	2622.5	235.9
Paros	111.3	134.8	183.1	236.9	319.5	359.8	377.7	349.8	282.4	212.0	153.5	119.9	2840.7	266.4
Kalamata	158.0	139.5	184.7	199.9	309.0	338.8	364.3	340.0	281.8	202.7	179.1	136.1	2833.9	228.2
Methoni	121.6	124.9	177.0	200.8	295.1	326.5	358.1	338.9	270.9	210.4	164.8	120.1	2709.1	238.0
Milos	93.7	87.6	166.5	206.3	327.0	389.2	424.0	399.4	320.6	195.4	161.9	95.8	2867.4	336.4
Rodos	136.7	142.9	204.4	247.1	314.3	353.4	388.1	375.1	315.5	238.6	183.8	143.3	3043.2	251.4
Kythira	153.8	134.2	176.9	216.3	301.6	349.7	365.9	344.6	285.1	208.1	168.4	132.1	2836.7	233.8
Souda	112.7	127.7	177.7	229.4	312.2	330.0	371.4	366.0	288.0	187.3	165.5	121.7	2789.6	258.7
Chania	112.6	127.6	176.6	228.4	318.0	355.7	393.2	368.7	279.3	186.6	165.9	116.3	2828.9	280.6
Rethymnon	110.8	132.3	157.0	218.0	309.0	335.0	373.1	350.2	263.7	166.1	165.8	112.9	2693.9	262.3
Heraklio	106.8	125.1	181.9	234.4	315.0	351.8	386.9	357.9	290.2	200.2	166.1	122.0	2838.3	280.1
Sitia	109.1	125.7	181.7	228.2	310.3	346.1	379.3	349.2	286.7	201.3	168.2	118.7	2804.5	270.2
Tymbakion	134.5	158.7	197.7	234.2	323.4	334.5	386.6	384.0	296.7	232.5	186.6	169.7	3039.1	252.1
Ierapetra	155.6	158.8	208.3	240.2	319.1	355.4	384.7	367.7	307.5	235.9	201.3	167.0	3101.5	229.1

coordinates and altitudes. The duration of bright sunshine was measured by the mean latitude Campbell-Stokes type sunshine recorder, during different periods of time, over 15 years, during the period 1960–1990. Unreliable or missing data were excluded from the present analysis.

In an attempt to predict and describe monthly, seasonal and annual sunshine duration in Greece, the data from the above relatively densely and uniformly distributed sunshine recording stations were used applying simple statistical methods and the RayMan model for radiation and bioclimate (Matzarakis et al., 2000). In addition, the ratio of the mean monthly duration of bright sunshine to the maximum possible duration (theoretical estimated) is investigated or determined.

The results are presented in form of tables and maps, and are compared to the true values listed in Table 2, in order to assess the level of any relationship.

3. Annual march of sunshine duration

The average monthly mean values of the hours of bright sunshine duration for the 37 stations are presented in Table 2. A detailed examination of Table 2 underlines some expected but never the less interesting points which could be summarized as follows. The annual march of the hours of sunshine duration seems to follow a simple variation with maximum sunshine values in July and minimum values in January and/or December. The occurrence of the maximum values in July (ranging from 220 to 400 hours) could be, because during this month the depressions developing and crossing the Greek region are almost missing, the Etesian winds system is quite frequent and persistent and the Azores subtropical high extension covering the broader north-eastern Mediterranean mean region. In addition, the value of the theoretical sunshine hours is higher in July than in August and June by 24 hours and 8 hours, respectively.

The minimum values of duration of bright sunshine hours occur in January and/or December. During these months the cyclonic (depressions) and frontal activity show their maximum frequency, and the theoretical sunshine values are comparatively much lower than those of the other winter months.

The maximum and minimum sunshine values over the region depend on synoptic and dynamic factors linked with cloudiness. Because of the different effect exerted by these factors in the structure and type of clouds over the region, there are some differences in the average sunshine hours at the various stations. Primarily, due to the north and north-eastward intensification of frontal activity, most pronounced during winter and spring, mean sunshine duration tends to increase toward the southern parts of the region. Here latitude is the most important factor in determining a station's sunshine regime, and the latitude must also be considered, however most of the mainland winter half-year cloudiness (sunshine) is governed by the passing of depression systems that should also affect mountain areas.

Differences between individual stations are most important in summer. At that time the maximum and minimum sunshine values tend to occur at higher and lower elevations, respectively. The effect of latitude is much less important than that of longitude in the bright sunshine duration.

On the other hand, sea-level pressure charts reveal that favourable synoptic conditions for continuously clear skies (Katsoulis and Kanteres, 1979), i.e. for consecutively large sunshine duration values, appear when a closed high pressure system is located over the middle Mediterranean Sea. In addition, the particular orientation of the anticyclonic extension systems (e.g. of Siberian or western Europe highs) with respect to Greece is at least partially responsible for the enhanced sunshine duration during the summer half year (Katsoulis and Kambezidis, 1987).

Furthermore, considering the mean monthly percentage of duration of bright sunshine with respect to the maximum possible (theoretical) duration (Table 3) we can see that these percentage ratios vary between 85% in July and August and 50% in March. The patterns indicated in Table 3 show two principal variations:

i) A general increase in percentage of sunshine ratios with increasing length of the day,
ii) A reduction of sunshine ratios from summer towards to autumn.

As the time length of days decreases, the percentage variability of sunshine becomes also smaller. The opposite occurs during the longer summer

Table 3. Percentage ratios of the duration of measured sunshine and theoretical possible

Stations	Year	Winter	Spring	Summer	Autumn
Komotini	0.53	0.41	0.47	0.66	0.54
Serres	0.53	0.37	0.50	0.67	0.52
Sedes	0.53	0.36	0.50	0.70	0.52
Mikra	0.51	0.32	0.51	0.65	0.49
Konitsa	0.51	0.40	0.46	0.62	0.52
Limnos	0.58	0.32	0.56	0.77	0.58
Ioannina	0.51	0.32	0.47	0.66	0.51
Larisa	0.55	0.31	0.53	0.71	0.55
Kerkyra	0.59	0.40	0.54	0.78	0.58
Mytilini	0.61	0.38	0.56	0.81	0.63
Lamia	0.57	0.35	0.54	0.74	0.56
Skyros	0.57	0.29	0.54	0.79	0.56
Patra	0.56	0.39	0.53	0.71	0.56
Aliartos	0.55	0.31	0.53	0.75	0.54
Chios	0.64	0.39	0.60	0.85	0.66
Argostolion	0.62	0.45	0.56	0.79	0.60
Araxos	0.60	0.42	0.57	0.74	0.62
N. philadelphia	0.63	0.40	0.59	0.83	0.62
Korinthos	0.60	0.39	0.56	0.77	0.61
Helliniko	0.62	0.42	0.58	0.80	0.62
Samos	0.65	0.43	0.59	0.83	0.68
Pyrgos	0.64	0.48	0.59	0.80	0.65
Syros	0.65	0.42	0.62	0.83	0.66
Naxos	0.59	0.37	0.55	0.75	0.62
Paros	0.64	0.40	0.61	0.83	0.63
Kalamata	0.64	0.48	0.58	0.80	0.65
Methoni	0.61	0.40	0.56	0.79	0.63
Milos	0.64	0.30	0.58	0.93	0.66
Rodos	0.68	0.46	0.64	0.86	0.72
Kythira	0.64	0.46	0.58	0.82	0.64
Souda	0.63	0.39	0.60	0.82	0.62
Chania	0.64	0.39	0.60	0.86	0.61
Rethymnon	0.61	0.39	0.57	0.82	0.58
Heraklio	0.64	0.38	0.61	0.85	0.64
Sitia	0.63	0.38	0.60	0.83	0.64
Tymbakion	0.68	0.50	0.63	0.85	0.69
Ierapetra	0.70	0.52	0.64	0.86	0.72

days. This variability reflects also the existing weather conditions during the different months and seasons. Physically, if the sky is completely clear, then the meteorological and astronomical (theoretical) sunshine durations become equal to each other. For completely overcast conditions, the meteorological (actual) sunshine duration is equal to zero.

4. Geographical distribution of bright sunshine duration

Until now, the demand for a preliminary base for solar irradiance estimation data in Greece has not been satisfactory made (e.g. Karapiperis et al., 1974; Macris, 1976; Katsoulis and Papachristopoulos, 1978). The present analysis attempts to remedy the deficiency and the results are summarized in Figs. 2 to 6. Figure 2 shows the mean annual distribution of bright sunshine; Figs. 3 to 6 show the winter, spring, summer and autumn distributions.

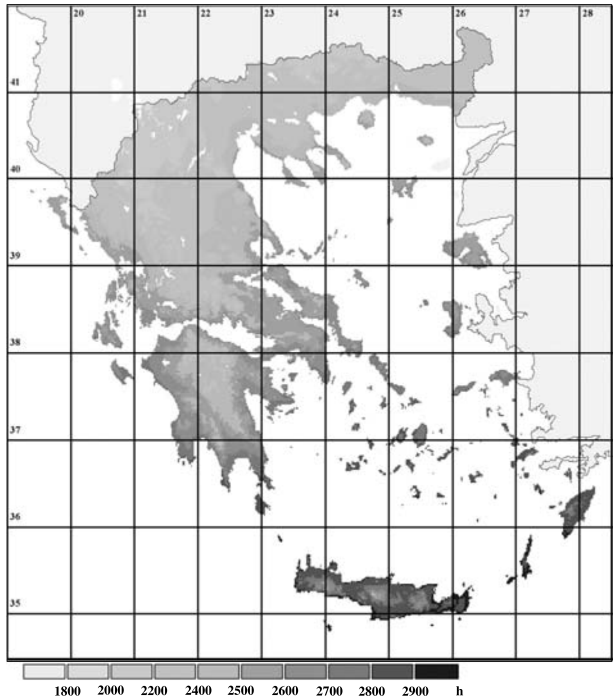

Fig. 2. Annual distribution of sunshine duration in the Greek region (in hours)

As already mentioned, the monthly, seasonal and annual distribution of sunshine and its variation (in time and space) over the Greek region has been analyzed subjectively and discussed in an earlier paper by Karapiperis et al. (1974). In this study, the seasonal and annual distribution of bright sunshine was made in an objective way applying a topographical model (with a resolution of $1/60$ degrees), which has been used previously in studies of the geographical distribution of climatic and bioclimatic parameters (Matzarakis, 1995; Matzarakis and Mayer, 1997; Matzarakis et al., 1998). The method and the used equations for annual and seasonal maps are described and discussed in Section 5. The results of these space and time sunshine duration distributions are displayed in the maps of Figs. 2 to 6.

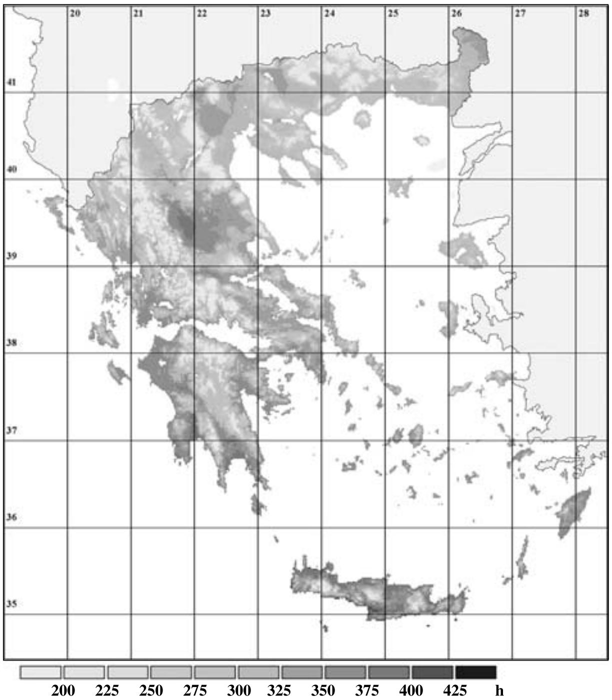

Fig. 3. Geographical distribution of sunshine duration during winter in the Greek region (in hours)

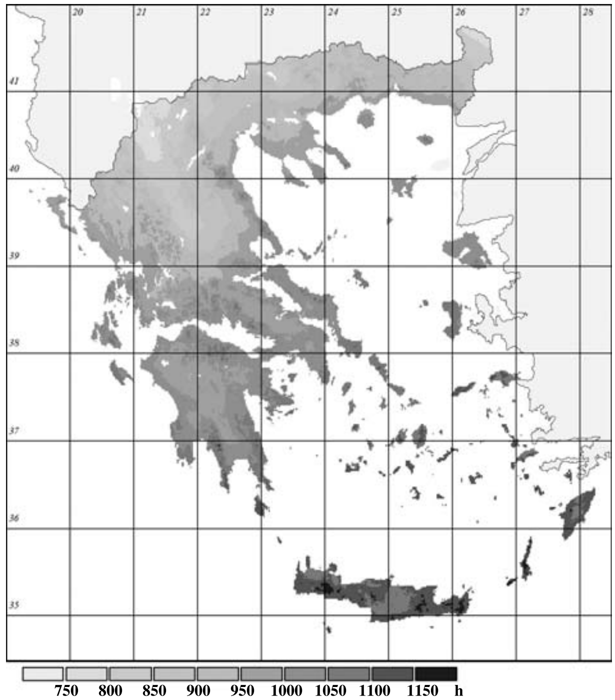

Fig. 5. Geographical distribution of sunshine duration during summer in the Greek region (in hours)

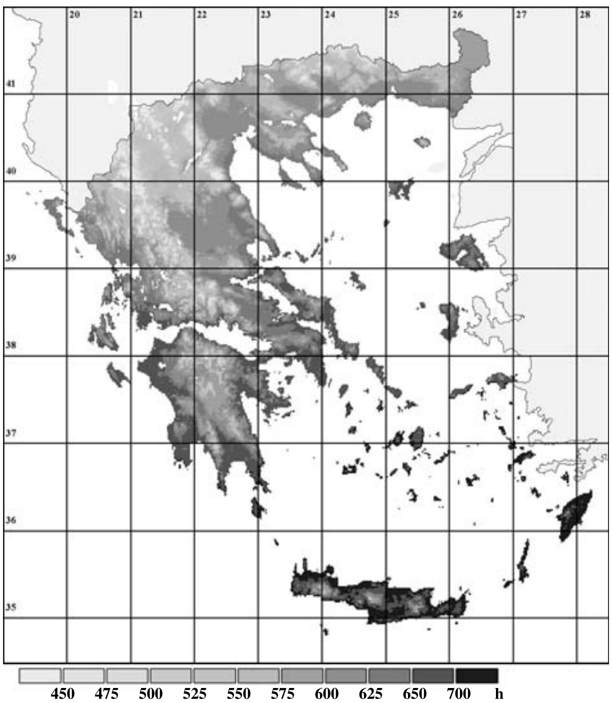

Fig. 4. Geographical distribution of sunshine duration during spring in the Greek region (in hours)

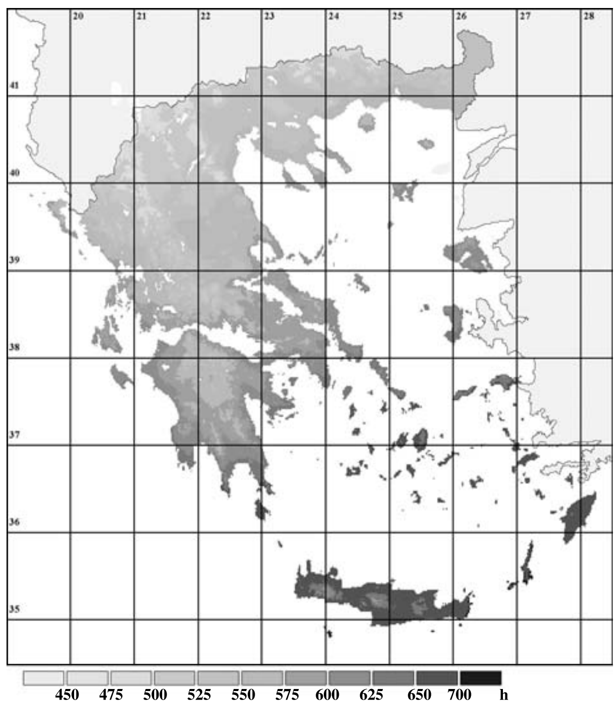

Fig. 6. Geographical distribution of sunshine duration during autumn in the Greek region (in hours)

Taking the year as a whole (Fig. 2), the duration of sunshine achieves its maximum over the southeastern and southern coastal and island areas, particularly in the southeast areas of the Aegean Sea, in the southeastern coasts of the Greek peninsula, and in the southern coasts of

Crete, followed by the islands near the western coast of Asia Minor and the coastal areas of the Attica (Athens) and its surrounding coastal areas. Specifically, the annual maximum of bright sunshine values are approximately 3100 hours observed in Rhodos and in Crete, and 2900 hours in Attica (Athens). The clear spells are distributed evenly about noon at all stations studied. The northern and central mountain regions receive less sunshine as a result of the orography and the developing and passage of winter disturbances from the west, and also because of the decrease in the length of the day with latitude. Low sunshine amounts due to the cloudiness in the western parts of Greece's mountainous regions associated with disturbances from Italy. In particular, the minimum sunshine occurs in the mainland of West Macedonia, Epirus and along the central mainland mountain regions, increasing gradually towards the coasts of the Ionian and Aegean Seas and from north to south.

During winter season, the distribution of bright sunshine seems to reach the highest values over southeastern Greece, particularly in the southeast parts of the Aegean Sea and in the southern regions of Crete, in the southern coastal parts of Peloponnese, and at the islands near the southwestern coasts of the Peninsula (Fig. 3). Where mean sunshine hours for the winter season range from 260 to 480 hours. The minimum values are observed over the northern and central mainland mountain regions of West Macedonia, Epirus and Central Greece (e.g. Ioannina, Aliartos, with approximately 280 sunshine hours).

In spring the sunshine duration appears to markedly increase in comparison with that of winter over the whole region because of the decreasing cyclonic activity. The minimum values are observed in the inland mountain areas of Epirus (Konitsa, 560 hours) and West Macedonia while the maximum values are obtained over the Dodecanesse islands (Rhodos, 760 hours). Also, the areas of Attica (around Athens) and Cyclades islands, as well over the southern coasts of Crete enjoy high values of bright sunshine (Fig. 4).

Regarding the dry summer season (Fig. 5), the minimum monthly sunshine occurs in the interior of West Macedonia and Epirus in north Greece and along the main mountainous parts of Central Greece, increasing gradually towards the coasts and from north to south. The maximum monthly values appear in the Aegean islands (more than 400 hours in July) and in Crete (more than 1050 hours for the season). The range of sunshine values ranges from 900 hours (Serres) and more than 1050 hours (in Skyros and Crete). High sunshine values are also recorded at the islands of Ionian Sea, decreasing towards the interior of the mainland.

Finally, during the autumn, the duration of bright sunshine records become lower than those of summer season (Fig. 6). This is due to the enhancement of developing and passing of disturbances from the west and the decrease in the length of the days with latitude; and the increased cloudiness associated with depressions from the western Mediterranean basin. The sunshine of autumn is lower than that of spring, since the theoretical sunshine hours of autumn are lower than spring's theoretical sunshine with about 50 hours. The minimum values (less than 650 hours) are recorded again over the north and central mountainous parts of the region, e.g. Epirus, W. Macedonia and Central Greece. The maximum values (higher than 700 hours) of sunshine duration are observed in Crete and Dodecanesse (Rhodos, around 740 hours).

Space does not permit here for showing maps for individual months such as those given in a previous publication (Karapiperis et al., 1974). However, a comparison of the results obtained by the present study with those given by other previous investigators exhibits similar patterns and characteristics of sunshine distribution over the region.

In general, the dynamic, synoptic and physical-geographical factors which are associated with the maximum and minimum bright sunshine values may be summarized as follows:

The maximum values of the summer half-year period occur under anticyclonic conditions and conditions favouring the developing of the Etesian wind system.

The minimum values, commonly during the cold half-year period, are the result of the development and passage of disturbances from the west and the decrease in the length of the day with latitude.

These maps can only show the broad-scale features of the geographical variation, and it would be incorrect to interpolate to a high degree of precision for particular localities.

In conclusion, accounting the above analysed overall picture of the sunshine duration, it is implied that the bright sunshine duration over the Greek region is quite higher than that of those the corresponding values recorded in other countries around the west and northwest of the Mediterranean basin at the same parallels (Biel, 1944; Landsberg, 1977).

Thus, the Greek region is quite convenient for the utilization of solar energy (Macris, 1976) more than other regions (with similar climate characteristics) and for tourist activities (investment and growth) for long lasting time periods of the year (Matzarakis, 1995).

5. Discussion

Average monthly, seasonal and annual sunshine duration values can be found with a good degree of accuracy using empirical formulae (Catsoulis, 1978). These equations depend on the distance from the nearest coast, the percentage land cover of the area around of each recording station (to a radius of 20 km), the altitude above sea level for any station location, the latitude and the longitude of the stations.

Close examinations of the maps (Figs. 2 to 6) showing the annual and seasonal distributions of the average means of the duration of bright sunshine brings forth some common interesting points which could be summarized as follows, according to those mentioned earlier in Section 4.

Firstly, as might be expected, the areas with the highest sunshine averages lie along the south coast. Secondly, as is not realized quite often, places further north have almost as high an average sunshine as the south coast areas, if (and only if) they lie near the coasts, especially the east coasts.

The areas with the lowest sunshine averages are those furthest inland and at the greatest height above mean sea level. Space here does not permit showing similar maps of the individual months, but those given in a publication by Karapiperis et al. (1974) exhibit the same characteristics.

The regularity of distribution suggests that it should be possible to work with our statistical-empirical equations (which have been also used for the construction of the geographical distribution in this investigation) from which sunshine coverages could be estimated using as variables:

a) the distance from the nearest coasts (in km), here in grid points (H),
b) the percentage of land cover around each station (radius 20 km) of each measuring station (X),
c) the height above sea level (in m) (Z),
d) the latitude of the station (φ), here in rel. coordinates,
e) the longitude of each station (λ), here in rel. coordinates,

Such equations have been determined here (for the year and for the four seasons) and the average annual sunshine in hours is given for any place in the Greek region with a fair degree of accuracy by the formula (given is also the regression coefficient r and the standard error SE):

$$\begin{aligned} S_{\text{annual}} &= 2248.2 - 0.2429 * Z + 0.1350 * X \\ &\quad - 0.1511 * H + 0.2177 * \lambda + 1.3585 * \varphi, \\ &\quad \text{and } r = 0.871 \text{ and } SE = 120.1 \text{ hours.} \end{aligned}$$

Similar equations can be found for each of the four seasons, namely:

$$\begin{aligned} S_{\text{wint.}} &= 303.1 - 0.1457 * Z - 0.0067 * X \\ &\quad + 0.1149 * H - 0.0619 * \lambda + 0.3132 * \varphi, \\ &\quad \text{and } r = 0.586 \text{ and } SE = 45.9 \text{ hours.} \\ S_{\text{sprin.}} &= 579.1 - 0.1091 * Z + 0.0271 * X \\ &\quad - 0.0100 * H + 0.0607 * \lambda + 0.3182 * \varphi, \\ &\quad \text{and } r = 0.889 \text{ and } SE = 26.2 \text{ hours.} \\ S_{\text{sum.}} &= 877.7 - 0.0691 * Z + 0.0700 * X \\ &\quad - 0.2745 * H + 0.1179 * \lambda + 0.3741 * \varphi, \\ &\quad \text{and } r = 0.858 \text{ and } SE = 47.9 \text{ hours.} \\ S_{\text{aut.}} &= 488.3 - 0.0572 * Z + 0.0446 * X \\ &\quad + 0.0185 * H + 0.1010 * \lambda + 0.3530 * \varphi, \\ &\quad \text{and } r = 0.843 \text{ and } SE = 35.8 \text{ hours.} \end{aligned}$$

Comparing the results obtained from the above equations with the true averages listed in Table 4, it was found that over half of the stations produce estimates within 0.3 hours per day of the correct value, that is, within about 20 minutes per day. Over 80% of the stations estimated lie within 0.5 hours per day of the observed values and the only exceptions are those which lie in the island of Crete in the extreme south and have less sunshine than would be indicated by the formulae. There

Table 4. Measured and estimated daily seasonal and annual sunshine duration (in hours)

Station	Winter		Spring		Summer		Autumn		Year	
	Meas.	Est.	Meas.	Est.	Meas.	Est.	Meas.	Est.	Meas.	Est.
Komotini	4.0	3.4	6.2	6.7	9.6	10.0	6.0	6.1	6.5	6.6
Serres	3.6	3.6	6.6	6.6	9.7	9.5	5.8	5.9	6.5	6.4
Sedes	3.5	3.4	6.6	6.8	10.1	10.3	5.8	6.1	6.5	6.7
Mikra	3.2	3.5	6.7	6.8	9.4	10.4	5.5	6.1	6.2	6.7
Konitsa	4.0	3.4	6.1	6.1	9.0	9.3	5.8	5.7	6.2	6.1
Limnos	3.2	3.5	7.4	7.2	11.1	11.1	6.5	6.7	7.1	7.1
Ioannina	3.1	3.4	6.2	6.2	9.5	9.6	5.7	5.8	6.2	6.3
Larisa	3.1	3.9	7.0	6.8	10.2	9.7	6.2	6.1	6.7	6.7
Kerkyra	4.0	3.8	7.2	7.0	11.3	10.6	6.5	6.3	7.2	6.9
Mytilini	3.8	3.6	7.4	7.4	11.7	11.3	7.0	6.9	7.5	7.3
Lamia	3.6	3.8	7.1	6.9	10.5	10.4	6.3	6.3	6.9	6.8
Skyros	2.9	3.7	7.0	7.4	11.3	11.4	6.3	6.9	6.9	7.4
Patra	3.9	4.0	6.9	7.2	10.2	10.8	6.3	6.5	6.8	7.2
Aliartos	3.1	3.9	6.9	7.1	10.7	10.7	6.1	6.5	6.7	7.1
Chios	3.9	3.8	7.8	7.5	12.1	11.4	7.4	7.0	7.8	7.4
Argostolion	4.5	4.1	7.4	7.3	11.4	11.1	6.8	6.7	7.5	7.3
Araxos	4.3	4.0	7.5	7.3	10.6	11.0	7.0	6.6	7.4	7.3
N. philadelphia	4.0	3.8	7.7	7.2	11.9	11.0	7.0	6.6	7.7	7.2
Korinthos	3.9	4.0	7.3	7.4	10.9	11.1	6.8	6.8	7.3	7.3
Helliniko	4.3	4.0	7.6	7.4	11.4	11.2	7.0	6.8	7.6	7.4
Samos	4.3	3.8	7.7	7.7	11.8	11.8	7.7	7.3	7.9	7.7
Pyrgos	4.8	4.2	7.7	7.4	11.4	11.0	7.3	6.7	7.8	7.3
Syros	4.2	4.0	8.1	7.7	11.9	11.8	7.4	7.3	7.9	7.7
Naxos	3.8	4.1	7.2	7.8	10.6	11.8	7.1	7.3	7.2	7.7
Paros	4.1	4.1	8.0	7.8	11.8	11.9	7.1	7.4	7.8	7.8
Kalamata	4.8	4.3	7.5	7.5	11.3	11.0	7.3	6.8	7.8	7.4
Methoni	4.1	4.2	7.3	7.6	11.1	11.5	7.1	7.0	7.4	7.6
Milos	3.1	3.9	7.6	7.7	13.2	12.0	7.4	7.3	7.9	7.7
Rodos	4.7	4.1	8.3	8.0	12.1	12.1	8.1	7.6	8.3	7.9
Kythira	4.7	4.1	7.6	7.7	11.5	12.0	7.3	7.3	7.8	7.8
Souda	4.0	4.3	7.8	7.9	11.6	12.0	7.0	7.4	7.6	7.9
Chania	4.0	4.4	7.9	7.9	12.1	11.9	6.9	7.4	7.8	7.9
Rethymnon	4.0	4.5	7.4	8.0	11.5	11.9	6.5	7.5	7.4	8.0
Heraklio	3.9	4.4	7.9	8.0	11.9	12.0	7.2	7.5	7.8	8.0
Sitia	3.9	4.5	7.8	8.1	11.7	11.9	7.2	7.6	7.7	8.0
Tymbakion	5.1	4.6	8.2	8.0	12.0	11.7	7.9	7.4	8.3	8.0
Ierapetra	5.3	4.5	8.3	8.2	12.0	12.2	8.2	7.7	8.5	8.2

are also some other areas where there is more or less sunshine than the formulae suggest. These are the plains of central and northeastern Greece, some islands of the Aegean Sea and the extreme northwestern parts of the Greek Peninsula. These are illustrated in Table 4 and in Figs. 7 to 11.

The five stations of Crete and the three (Pyrgos, Patras, Kalamata) stations in the extreme southwest areas together with the islands of Naxos, as well as at Micra (Thessaloniki) and New Philadelphia (Attica), show the biggest deviation from the straight lines grouping. Table 4 and Figures 7 to 11, show relationships and correlations of the r^2 values between actual and estimated values.

The striking features here are the outstanding high sunshine values of Patras and Araxos and the low values of Serres, Konitsa and Ioannina, these low values can be explained by the shading effects of hills and mountains (Furmage, 1970).

Most meteorological factors vary considerably over small distances, but sunshine is one of the few which does not. These empirical approaches seem to give a close approximation to average annual and seasonal sunshine figures for anywhere in the Greek region, which is not subject

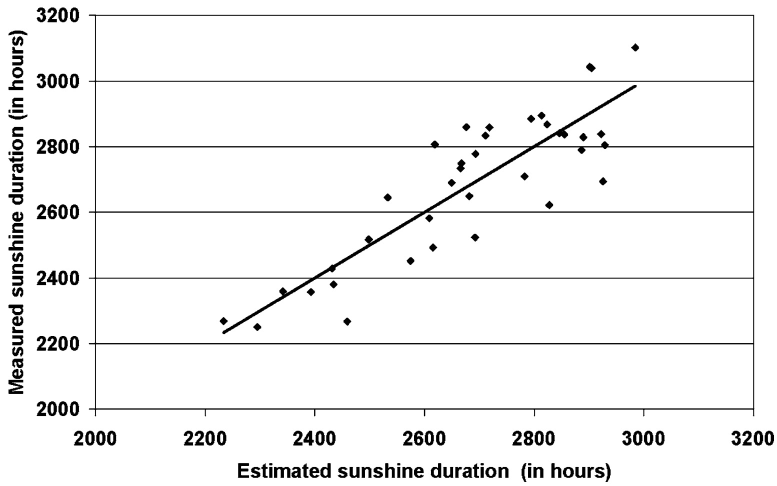

Fig. 7. Comparison between measured and estimated annual sunshine duration (in hours), r = 0.87 and RSME = 9.90

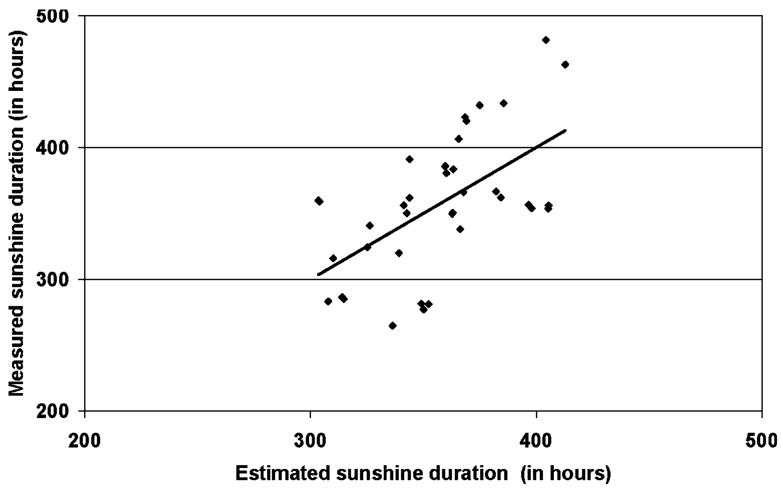

Fig. 8. Comparison between measured and estimated sunshine duration for winter (in hours), r = 0.58 and RSME = 6.15

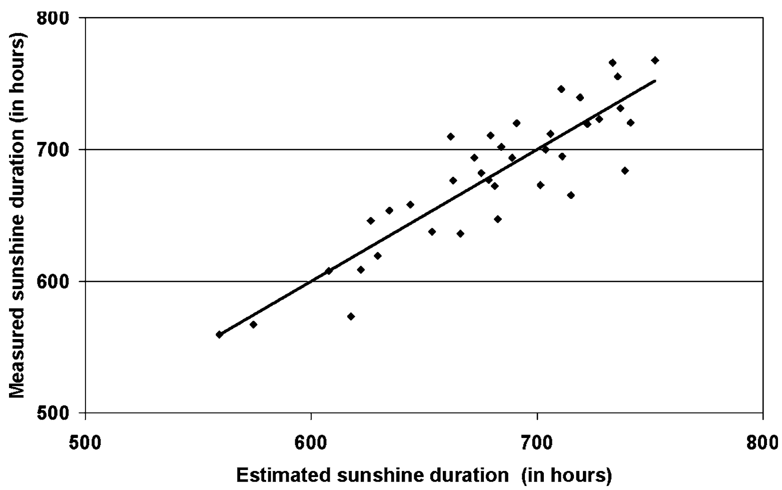

Fig. 9. Comparison between measured and estimated sunshine duration for spring (in hours), r = 0.89 and RSME = 4.69

to physical shading due to proximity of mountains, hills, buildings and/or other obstacles. The comparison between actual and estimated values gives strongly relationships (Table 4 and Figs. 7 to 11) as well as because of the relatively adequate and high correlations, when height and coordinates have been adjusted for. The regression coefficients r and the root square mean error RSME are for the annual comparison r = 0.87 and RSME = 9.9 and for the seasons for the

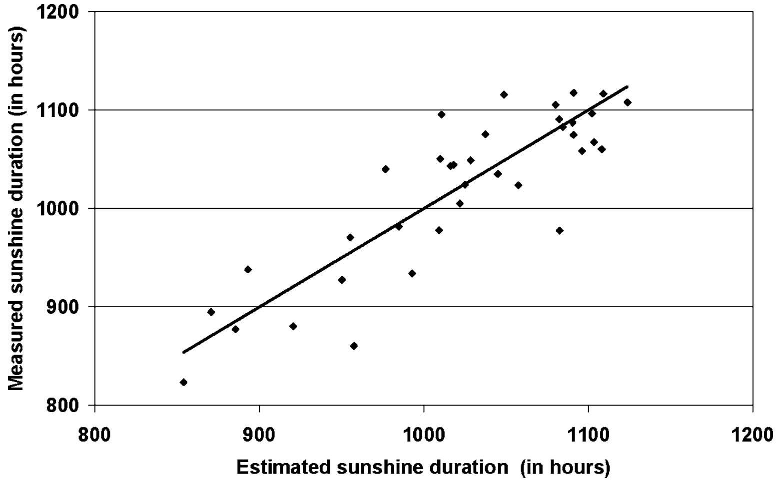

Fig. 10. Comparison between measured and estimated sunshine duration for summer (in hours), r = 0.86 and RSME = 6.22

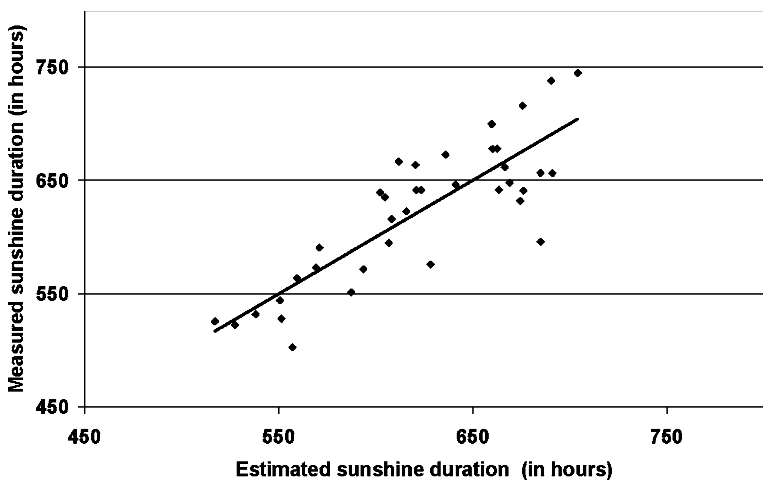

Fig. 11. Comparison between measured and estimated sunshine duration for autumn (in hours), r = 0.84 and RSME = 5.33

Winter with r = 0.7 and RSME = 6.15 and the remaining seasons are the correlation coefficients lying between 0.84 and 0.89 and the RSME from 4.69 to 6.22.

6. Concluding remarks

The use of a topographic model to analyse and examine the distribution of bright sunshine hours for conditions in the Greek region, gives an objective way to identify the spatial and temporal variation of this useful climate element. The results obtained by the model do not show significant divergence in comparison with the results of previous studies carried out by other subjective statistical methods. So, we conclude that they reflect the real sunshine conditions of the Greek region.

The relatively small differences between observed and estimated average annual and seasonal sunshine values were attributed to the following factors:

i) Near sunrise and sunset, during which radiation is too weak to activate the sunshine recorder is variable, depending on water vapour and turbidity content of the atmosphere.
ii) Stations are in different physicogeographical locations, and so, they are subject to different atmospheric conditions for the sunshine measurements.

Finally the main results of this study are as following:

a) The annual march of sunshine is simple with maximum values in July and minimum in January and/or December. The maximum values occur in July, because in this month the depressions from the west are almost entirely missing and the theoretical sunshine is greater that of the other summer months.

Concerning the minimum values these occur in January and/or December, since during these months cyclonic and frontal activity have their maximum frequency.

b) Favourable synoptic weather conditions for clear skies and lasting sunshine duration are the closed and/or extended high pressure systems over or near the Greek region.
c) The geographical distribution of sunshine duration shows minimum values in the northern interior mountain mainland areas (W. Macedonia, Epirus, Central Greece), increasing gradually towards the coasts of the Ionian and Aegean Seas and from north to south.
d) The most pronounced bright sunshine duration was recorded in the southeastern islands of the Aegean and over the southern coasts of Crete.
e) The estimated bright sunshine duration hours and their spatial and temporal distribution and variation appear to have strong relationship and almost similar pattern characteristics to those of actual values.

In conclusion, even though statistical analysis applied is only to Greek sunshine data, the distribution and the overall patterns of sunshine duration seem to remain unchanged during the last 40 years. The analysis shows that it would probably be useful to extend the investigation to include cloudiness for a longer period (from HNMS has satellite and radar data) to relate sunshine to cloudiness and to determine if any effect of CO_2 on changes in cloudiness and sunshine exist. Satellite and radar data will have to be used to investigate such changes.

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