SMGroup

SM Journal of Biometrics & Biostatistics

Research Article

Statistical Analysis and Inter-Comparison of Solar UVB and Global Radiation for Athalassa and Larnaca, Cyprus

Pashiardis S[1], Kalogirou SA[1]* and Pelengaris A[2]

[1]*Department of Mechanical Engineering and Materials Science and Engineering Cyprus University of Technology, Limassol, Cyprus*

[2]*Department of Cyprus Public Works, Ministry of Transport Communications and Works, Strovolos Avenue 165, 2048 Strovolos, Cyprus*

Article Information

Received date: May 05 2017

Accepted date: May 10 2017

Published date: May 16 2017

***Corresponding author**

Kalogirou SA, Department of Mechanical Engineering and Materials Science and Engineering Cyprus University of Technology, Limassol, Cyprus, Tel: +357-2500-2621; Fax: +357-2500-2637; Email: soteris.kalogirou@cut.ac.cy

Keywords Broadband UVB Irradiance; Statistical Analysis; Clearness Index; Frequency Distribution; Transparency; Statistical Relationships; Cyprus

Abstract

A statistical analysis and inter-comparison of the broadband ultraviolet-B (UVB) radiation at two sites in Cyprus representing two different climate regimes of the island (Athalassa-inland plain vs Larnaca-coastal location) covering the period January 2013-December 2015 is presented. Mean annual and mean monthly daily totals of the UVB irradiation and their frequency distribution at both sites are computed and discussed. Daily maximum of hourly average irradiance values occur in July, 2.09 W m^{-2}, and minimum, 0.47 W m^{-2}, in December at solar noon at Athalassa. The respective values at Larnaca are slightly higher (2.48 W m^{-2} and 0.67 W m^{-2}, respectively). UVB daily values follow the pattern of the solar altitude angle; the total accumulated UVB irradiation along a mean year reaches 10.27 MJ m^{-2} at Athalassa and 13.49 MJ m^{-2}; maximum stability of UVB takes place at midday hours during the summer. Large fluctuations of the daily UVB irradiation are observed in the spring months and November, which are mainly due to unstable meteorological conditions during the transition from cold to warm weather and vice versa. During summer the daily UVB radiation exceeds the value of 70 kJ m^{-2} at Larnaca and 55 kJ m^{-2} at Athalassa, while during the winter season the lowest is about 5 kJ m^{-2} at both stations. The UVB potential and extraterrestrial irradiation has also been calculated in order to estimate the attenuation of UVB radiation through the atmosphere. During summer the UVB transmittance is higher than in winter with a maximum value of 9% in July and a minimum of about 4% in December. Statistical relationships between UVB and other radiation components (UVA and global radiation) were established.

Introduction

Ultraviolet (UV) radiation covers wavelengths of the electromagnetic spectrum between 100 and 400 nm and it constitutes 8.73% of the total extraterrestrial solar spectrum irradiance. Within the UV radiation spectrum three zones are distinguished in relation to the effects that the radiation produces on living organisms: UVC (100-280 nm), UVB (280-315 nm) and UVA (315-400 nm) [1]. UVC does not reach the earth surface since it is absorbed completely by the ozone layer in the stratosphere. UVB is mostly absorbed by the stratospheric ozone layer. In the upper atmosphere, the UVB irradiance amounts to 1.3% of the solar constant [2]. The harmful effects of UVB are associated with skin cancer (melanoma) and eye diseases (cataracts) [3]. The effects over the skin depend on the duration of the exposure to sunlight. Severe skin overexposure produces severe sunburn that causes heat, erythema and other symptoms approximately 16 hours after exposure to natural sunlight [4]. UVA undergoes only minimal absorption by stratospheric ozone layer and is associated with the photo-aging of the skin, the immunosuppression of the skin immune system and the potential enhancement of the negative effects of UVB exposure. On the other hand, the benefit of human exposure to UV radiation is the synthesis of vitamin D in the skin. This synthesis is achieved with very low doses of UV radiation, such that a daily exposure of 10-15 min of the face, arms and hands at the intensity of the radiation received in Northern Europe is sufficient [5].

UV radiation on the Earth's surface varies widely and depends mainly on latitude, solar elevation, ozone column and local atmospheric conditions. The emission of certain gases due to human activity is known to alter the composition of the atmosphere. Some of the most serious damage caused is the reduction of the ozone layer in the stratosphere, causing a corresponding increase in ultraviolet radiation [6]. Measurements in Italy and England indicate that UVB incidence increased with decreasing ozone amount at fixed solar zenith angles [7-8].

In spite of the important role of UVB, few radiometric stations measure systematically the UVB solar irradiance in the Mediterranean region. A network of UV stations was established in Greece [9], Spain [10-11], Israel [12] and Egypt [13]. In Cyprus, UV radiation is measured currently at two locations: Athalassa (inland) and Larnaca (coastal place) [14-15].

OPEN ACCESS

ISSN: 2573-5470

Various authors have analyzed the relation between solar UV and global radiation. Martinez-Lozano et al [16]. studied UV (A+B) irradiance values in Valencia in the period 1991-1994. Foyo-Moreno et al [17]. analyzed UV and global irradiance in Granada. Cañada et al. [18] studied UV irradiance in Valencia and Córdoba in relation to the clearness index, the relative optical air mass, the time of year and the total irradiance on a horizontal surface. Mantis et al. [19], Koronakis et al. [20], Kudish and Evseev [21], Kudish et al. [12], Jacovides et al. [14-15, 22] performed statistical analysis of various components of UV radiation and global irradiances in Athens (Greece), Beer Sheva (Israel) and Athalassa (Cyprus), respectively.

In recent decades, radiative transfer and theoretical models have been developed that can be used to predict UV radiation when experimental data are not available. Neural networks are also applied for the estimation of UV irradiance [23-24]. Some authors use empirical models which are simpler, more manageable and understandable [25-26].

The European Cooperation in Science and Technology (COST)-Action 713 has tested a number of models for UVB forecasting using multiple scattering models rather than radiative transfer models [27]. The results of these simulations were also published in the final report of the COST Action 713 [28]. A second COST Action (COST-726) was established later to assess the long term changes and climatology of UV radiation over Europe [29]. UVB climatology was also the subject of a number of studies in the Mediterranean region [10,12,15,21-22,30-37].

An assessment of the solar radiation climate of the Cyprus environment was presented by Jacovides et al. in 1993 [38]. Kambezides [39] presented the 'Typical Meteorological Year' for Nicosia. More recently, Kalogirou et al. [40] presented a statistical analysis and inter-comparison of the solar global radiation at the above two sites in Cyprus using measurements of 21 months at both sites. The common feature of all the above studies is that they rely mostly on measurements of solar radiation carried out in the actinometric stations of Athalassa and Larnaca.

This work constitutes the second UVB analysis in the island of Cyprus. The first analysis of UVB and UVA was done by Jacovides et al. [15] using measurements for the period 2004-2006 but with different radiometers carried out at Athalassa. With the recent measurements, there is a chance to compare the levels of UVB between the two periods. This is also essential because of the fact that the atmospheric conditions in the area favour dry summers and cold winters, high air temperatures and low vapour pressure values at midday in summer time which affect the transmition of UVB through the atmosphere. In this work we analyze hourly UVB and global irradiance data on a horizontal plane and perform an inter-comparison study between the two locations in Cyprus as well as between other sites in the Mediterranean region.

Topography, Climatology, Measurements and Quality Control

Table 1: Site parameters for the two meteorological stations.

Site	Location	Latitude	Longitude	Altitude (m,m.s.l)
Athalassa	inland	35.141^0 N	33.396^0 E	165
Larnaca	coastal	34.873^0 N	33.631^0 E	1

Topography and climate characteristics of the two sites

The radiation data on which this study is based are being monitored at two meteorological stations: one located at Athalassa, an inland plain location and the other one at Larnaca Airport which is near the coast (Figure 1). The site parameters of the two stations are listed in Table1.

The climate of both stations is typical Mediterranean with mild winters (mean seasonal air temperature of about 12 ˚C at Larnaca and 10.5 ˚C at Athalassa) and warm summers (mean seasonal air temperature of 27.5 ˚C at Larnaca and 29.5 ˚C at Athalassa). At Larnaca Airport sea-breeze cells develop in late spring and summer. Although Athalassa is an inland location, a westerly sea-breeze is mainly noticeable during the summer time blowing from the Morphou bay between the mountainous ranges of Pentadactylos and Troodos (Figure 1). The annual rainfall is about 320 mm at Athalassa and about 340 mm at Larnaca. Most of the rainfall occurs between October and March; summer months are mostly dry. The two sites are characterised by relatively high global and horizontal beam radiation intensities. The average annual sunshine duration is 3332 hours for Athalassa and slightly higher at Larnaca (3368 h). All the above climatic averages refer to the 1981-2010 period.

The annual average daily global radiations exceed 18.5 MJ m^{-2} at the two sites, whereas the horizontal beam radiation is 13.1 MJ m^{-2} for Athalassa and 14.2 MJ m^{-2} for Larnaca, respectively. Consequently, the fraction of the beam component of the global radiation is relatively high at both sites, viz., the annual average daily fraction is >0.600 at the two sites. Comparing the two sites it seems that Larnaca has slightly higher rates of global radiation than Athalassa, since the average yearly cumulative global irradiation is 6763 MJ m^{-2} for Athalassa and 7274 MJ m^{-2} for Larnaca. The monthly average frequency of days according to the classification of the magnitude of the daily clearness index K_T (daily global to daily extraterrestrial radiation), showed that both clear and partially cloudy days exceed 80% annually (K_T>0.35) [40].

Measurements and quality control processes

The period for presenting the data in both stations is January 2013 until December 2015 (i.e., 3 years), when both stations operated simultaneously, so as to allow for comparison of the different variables of solar and terrestrial radiation. Measurements of total

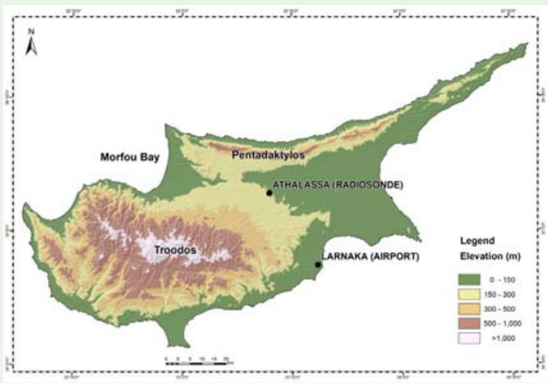

Figure 1: Map of Cyprus showing the location of the two radiometric stations.

solar irradiance on a horizontal surface were taken with Kipp&Zonen CM11 pyranometers whose spectral range is from 285 to 2800 nm. Both stations are equipped with Kipp&Zonen UVS-AB-T broadband radiometers with spectral range 280 to 315 nm (UVB) and 315 to 400 nm (UVA). The radiometers have directional response up to 70^0solar zenith angles (θ_z) less than 2.5%. All the sensors are factory calibrated, in accordance with the World Radiometric Reference (WRR). Global radiation instruments are calibrated outdoor against standard references at irregular time intervals during the study period. The errors involved in the radiation measurements are found to be less than ±2% for the normal incidence beam irradiance and ±3% for the global irradiance.

A Campbell Scientific Instruments data-logger, located at each site (Model CR10), monitors and stores the data at 10-min intervals (the meters are scanned every 10-seconds and average, maximum, minimum and instantaneous values at 10-min intervals are calculated and stored). The stored data are downloaded to a desktop computer periodically. The data refer to the Local standard Time (LST=GMT+2). About 5% of the data values are missing because of some problems with the instruments and some defects and maintenance in the data acquisition systems. The validity of the individual measurements was checked in accordance with WMO recommendations [41] and other tests proposed by various authors [42-44]. Details about the quality control procedures used in this study are given by Pashiardis and Kalogirou [45]. All data that do not meet the conditions specified by the suggested tests are not used in the study.

Regarding the UVB irradiance the following upper limit was applied as suggested by Miguel et al. [46]:

$$UVB \leq 1.2 * UVB_0 \quad (1)$$

where, UVB is the measured value and UVB_0 is the horizontal extraterrestrial solar UVB irradiance $G_{scUVB} = 18.67$ W m^{-2} [47]. The measurements of both stations were less than the horizontal extraterrestrial solar UVB irradiance during the whole period of measurements. The values of UVB irradiance during night were close to zero. No other errors were detected. Long missing data were detected during the first two months of 2013 and the period 8th August-21st September of 2015 at Larnaca. Furthermore, the hourly and daily UVB data were checked against a second UVB broadband sensor installed at Athalassa. There was a very good agreement between the two instruments.

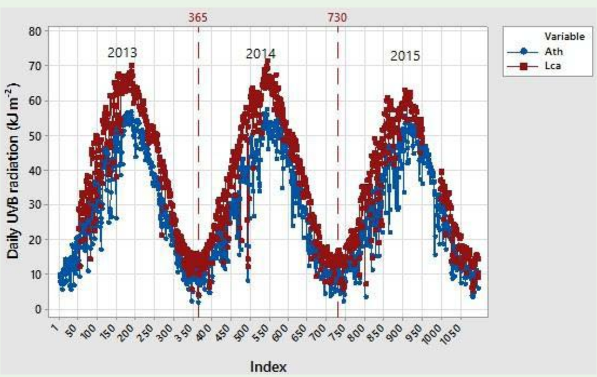

Figure 2: Time series plot of daily UVB solar irradiation during the period 2013-2015 at Athalassa and Larnaca.

Table 2: Relationships between hourly UVB irradiance (W m^{-2}) and daily UVB_d irradiation (in kJ m^{-2}) measured with different sensors at Athalassa.

Variabley	*Variablex*	*Equation*	*R²*
UVB	*UVB_SKU*	$y = -0.01012 + 1.050x$	*0.99*
UVB	*CUVB*	$y = 0.1564 + 34.34x$	*0.98*
UVBd	*UVBd_SKU*	$y = -0.6721 + 1.061x$	0.99
UVBd	*CUVBd*	$y = 3.983 + 37.62x$	0.99

Regarding the quality control of the daily UVB radiation data, daily values were rejected in case of incomplete data during the day. The time series plots of the daily values of UVB irradiation for both stations are shown in Figure 2. The figure indicates that the ascent during the first months of each year is very irregular with fluctuations, while the descent is smoother. During summer the daily UVB radiation exceeds the value of 70kJ m^{-2} at Larnaca and 55 kJ m^{-2} at Athalassa, while during the winter season the lowest is about 5kJ m^{-2} at both stations. Slightly lower values were recorded in the year 2015 at both stations, which can be attributed to the higher amounts of aerosols in the atmosphere. The year 2015 is characterized as an extremely dry year with more frequent dust episodes over the island (dust from the deserts of Middle East and Sahara), increasing therefore the aerosols in the atmosphere which affect the absorption of the UVB radiation.

The station at Athalassa is also equipped with two additional UVB sensors, i.e., a broadband UVB SKU-430 sensor from Skye Instruments company and a narrowband CUVB1 at λ=306 nm from Kipp & Zonen. The quality control can be also extended by comparing their hourly and daily values between the said sensors. Figure 3 shows the daily values of UVB as function of Julian day which were obtained from the three different types of UVB sensors. As indicated in the graph the broadband sensors show a very good agreement. The CUVB1 sensor can be used to estimate the erythemal irradiance (UVER). The hourly and daily relationships between the three sensors are given in Table 2. The characteristic of these relationships is that the coefficient of determination is close to one.

Results and Discussion

Data variation

Global solar radiation and total UVB radiation have been analysed and compared in this study. Figure 4a shows temporal evolution of

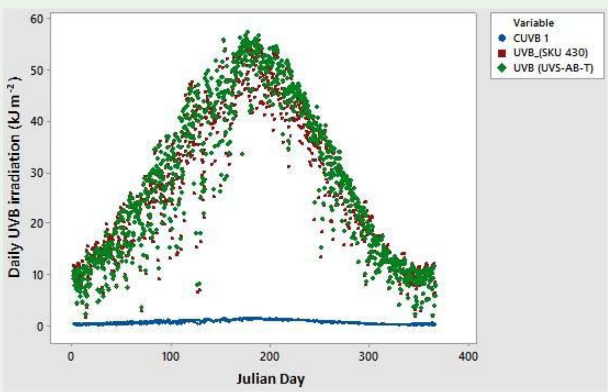

Figure 3: Daily values of UVB irradiation (in kJ m^{-2}) at Athalassa, obtained from two broadband UVB sensors (SKU 430-Skye Instruments and UVS-AB-T-Kipp&Zonen) and one narrowband CUVB1 at λ=306 nm from Kipp&Zonen.

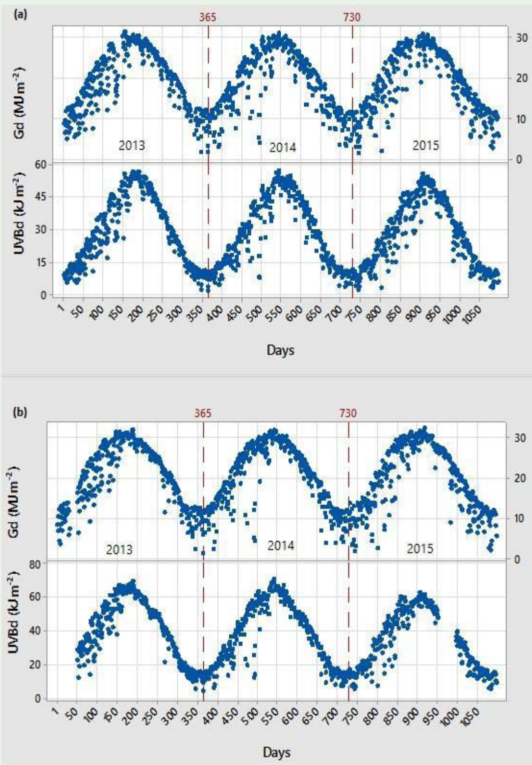

Figure 4: Co-variability of daily measured UVB values (UVB_d) and daily global horizontal solar radiation (G_d) during the period 2013-2015 at a) Athalassa and b) at Larnaca.

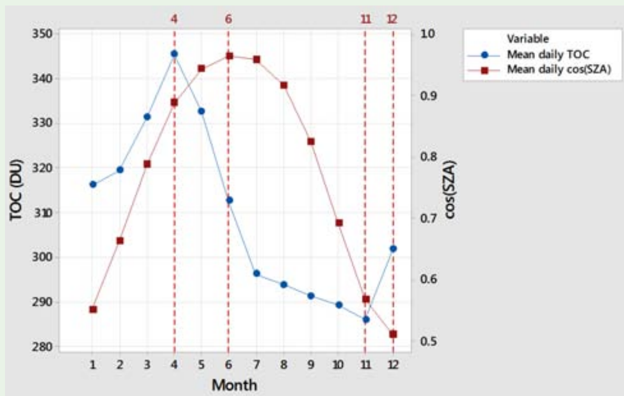

Figure 5: Annual cycle of monthly mean daily Total Ozone Column **(TOC)** in Dobson Units **(D.U.)** and the mean of the cosine of the midday solar zenith angle.

UVB and global solar radiation at Athalassa. A similar graph with slightly higher values was obtained at Larnaca (Figure 4b). Data reveal a common evolution shape with maxima in summer and minima in winter, mainly due to the daily minimum solar zenith angle and day-length (astronomical factors) variation during the year (Figure 5). Large fluctuations in the spring months and November are mainly due to unstable meteorological conditions during the transition from cold to warm weather and vice versa. The maximum of daily global solar horizontal irradiation is reached in June or July and is around 31 MJ m^{-2} at Athalassa and around 32 MJ m^{-2} at Larnaca.

Statistical analysis of hourly UVB irradiance

Table 3: Statistical estimators of the mean hourly UVB irradiance (W m^{-2}) in July, under all sky conditions, for the period 2013-2015, for a) Athalassa and b) Larnaca.

a) Athalassa

Hour	N	Mean	StDev	Coef. Var. (%)	Min	Q1	Median	Q3	Max	IQR	P_5	P_{95}
6	93	0.064	0.011	16.51	0.029	0.057	0.065	0.071	0.088	0.014	0.047	0.082
7	93	0.205	0.03	14.7	0.11	0.184	0.207	0.222	0.266	0.038	0.158	0.258
8	92	0.53	0.054	10.18	0.378	0.495	0.532	0.568	0.639	0.073	0.433	0.624
9	92	0.989	0.073	7.37	0.765	0.949	0.986	1.036	1.138	0.087	0.859	1.109
10	92	1.48	0.093	6.28	1.085	1.433	1.48	1.546	1.663	0.113	1.318	1.619
11	92	1.884	0.1	5.3	1.515	1.837	1.88	1.958	2.086	0.12	1.7	2.038
12	92	2.091	0.106	5.08	1.728	2.037	2.101	2.166	2.295	0.13	1.89	2.252
13	92	2.052	0.142	6.92	1.455	2.004	2.084	2.142	2.283	0.138	1.69	2.207
14	92	1.769	0.181	10.21	1.076	1.729	1.82	1.883	1.992	0.154	1.37	1.949
15	92	1.331	0.218	16.35	0.517	1.312	1.41	1.457	1.528	0.145	0.754	1.506
16	92	0.898	0.122	13.56	0.184	0.859	0.937	0.962	1.011	0.103	0.643	1.002
17	92	0.491	0.047	9.54	0.259	0.472	0.504	0.521	0.559	0.049	0.394	0.541
18	92	0.192	0.019	10.03	0.119	0.181	0.194	0.203	0.237	0.022	0.158	0.222
19	92	0.075	0.01	13.77	0.04	0.07	0.075	0.081	0.106	0.012	0.059	0.092

b) Larnaca

Hour	N	Mean	Standard Dev	Coef. Var. (%)	Min	Q1	Median	Q3	Max	IQR	P_5	P_{95}
6	93	0.073	0.016	21.35	0.04	0.061	0.072	0.083	0.108	0.022	0.048	0.105
7	93	0.219	0.054	24.81	0.132	0.18	0.204	0.269	0.352	0.09	0.154	0.332
8	93	0.58	0.108	18.6	0.375	0.503	0.564	0.683	0.824	0.179	0.431	0.787
9	93	1.102	0.152	13.83	0.707	0.994	1.091	1.227	1.421	0.233	0.89	1.377
10	93	1.687	0.178	10.56	1.184	1.559	1.693	1.831	2.064	0.272	1.408	2.003
11	93	2.186	0.186	8.49	1.632	2.047	2.204	2.324	2.583	0.278	1.868	2.499
12	93	2.48	0.179	7.21	2.03	2.343	2.492	2.61	2.854	0.268	2.151	2.767
13	93	2.487	0.162	6.52	2.1	2.366	2.518	2.621	2.805	0.255	2.2	2.726
14	93	2.208	0.144	6.54	1.888	2.098	2.211	2.33	2.52	0.232	1.947	2.42
15	93	1.713	0.154	8.98	0.778	1.636	1.697	1.803	1.999	0.167	1.528	1.922
16	93	1.127	0.126	11.19	0.565	1.05	1.146	1.213	1.345	0.163	0.921	1.321
17	93	0.602	0.087	14.43	0.376	0.533	0.616	0.664	0.75	0.131	0.438	0.732
18	93	0.225	0.055	24.38	0.085	0.183	0.239	0.27	0.306	0.086	0.115	0.294
19	84	0.088	0.022	24.76	0.037	0.07	0.093	0.103	0.147	0.034	0.053	0.118

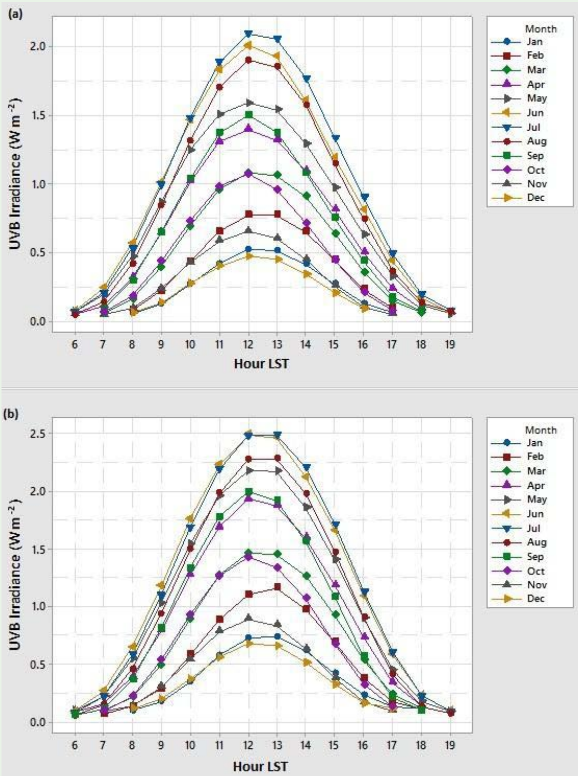

Figure 6: Daily evolution of the monthly mean hourly UVB irradiance (W m^{-2}) for the period 2013-2015 at a) Athalassa and b) Larnaca.

A statistical study of the most representative UVB indices for each month of the year has been carried out and the UVB accumulated values have been evaluated because they are very useful in the studies of effects on human beings.

Table 3 shows the hourly statistical estimators for July for both stations. The statistical parameters presented in the Table are: number of data (*N*), arithmetic mean (*Mean*), standard deviation (*StDev*), coefficient of variation (*CV* in %), minimum (*Min*), first quartile (*Q1*), *median*, third quartile (*Q3*), maximum (*Max*), interquartile range (*IQR*), percentile 5 (P_5) and percentile 95 (P_{95}). It can be observed that the median values are slightly higher than the average ones at least during the middle hours of the day, which suggest that the average hourly UVB distribution is approaching the normal one.

The difference between the *Q3* quartiles and the maximum values are low, with the highest ones not exceeding 0.14 W m^{-2} for Athalassa and 0.26 W m^{-2} for Larnaca; this result shows that the maximum values are representative of the UVB irradiance at midday. On the other hand the differences between *Q1* quartiles and minimum values are high mainly around midday.

The UVB variability has been studied by means of the coefficient of variation (*CV*). As it can be seen in Table 3, the *CVs* in July are low during the midday (5-7%) at both stations, indicating a high stability along these hours in summer. Furthermore, *CVs* fluctuate between 5 and 16.5% at Athalassa, while at Larnaca slightly higher values are observed (6.5-25%). The standard deviation is higher along midday hours and symmetrically distributed around solar noon during the summer months. This could be explained by a minor presence of clouds in the summer months that lead to a high stability.

Table 4: Accumulated hourly UVB values for a mean day of each month (kJ m^{-2}), during the period 2013-2015 at a) Athalassa and b) Larnaca.

a) Athalassa

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
6-May				0.18	0.23	0.26	0.23	0.16					0.22
7-Jun			0.21	0.58	0.91	1.12	0.97	0.66	0.32	0.23	0.17		0.7
8-Jul	0.21	0.28	0.78	1.72	2.6	3.17	2.88	2.17	1.39	0.89	0.5	0.22	1.67
9-Aug	0.66	1.07	2.2	4.03	5.71	6.8	6.44	5.19	3.71	2.46	1.35	0.69	3.63
10-Sep	1.63	2.63	4.69	7.69	10.19	12.07	11.76	9.91	7.44	5.08	2.87	1.67	6.75
11-Oct	3.13	4.98	8.13	12.39	15.61	18.64	18.55	16.04	12.37	8.61	4.97	3.1	10.83
12-Nov	5.01	7.76	12.01	17.4	21.31	25.85	26.07	22.86	17.76	12.47	7.32	4.79	15.35
13-Dec	6.86	10.53	15.83	22.15	26.85	32.77	33.46	29.52	22.7	15.91	9.48	6.4	19.67
13-14	8.35	12.87	19.09	26.07	31.5	38.55	39.83	35.17	26.58	18.48	11.09	7.64	23.24
14-15	9.32	14.47	21.39	28.98	34.98	42.82	44.62	39.28	29.28	20.08	12	8.38	25.78
15-16	9.78	15.3	22.68	30.77	37.25	45.74	47.85	41.94	30.85	20.84	12.37	8.71	27.32
16-17	10.01	15.64	23.21	31.61	38.43	47.31	49.62	43.26	31.47	21.12	12.54		28.2
17-18			23.42	31.92	38.85	47.93	50.31	43.73	31.74				28.64
18-19					39.04	48.16	50.59	43.98					28.88

b) Larnaca

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
6-May				0.31	0.34	0.33	0.26	0.19	0.21				0.29
7-Jun		0.24	0.36	0.85	1.13	1.27	1.05	0.71	0.61	0.33	0.33		0.88
8-Jul	0.36	0.71	1.12	2.24	3.1	3.6	3.14	2.36	1.91	1.11	0.81	0.4	2.06
9-Aug	0.98	1.74	2.9	5.08	6.8	7.84	7.11	5.73	4.83	3.05	1.89	1.11	4.45
10-Sep	2.23	3.84	6.12	9.67	12.35	14.17	13.18	11.1	9.64	6.38	3.83	2.44	8.32
11-Oct	4.3	7.02	10.69	15.74	19.39	22.18	21.05	18.22	16.03	10.92	6.63	4.45	13.52
12-Nov	6.91	10.98	15.95	22.7	27.22	31.13	29.98	26.4	23.21	16.05	9.83	6.88	19.45
13-Dec	9.57	15.15	21.16	29.44	35.02	39.98	38.93	34.6	30.11	20.86	12.83	9.25	25.29
13-14	11.79	18.66	25.72	35.18	41.69	47.61	46.88	41.71	35.75	24.71	15.09	11.11	30.24
14-15	13.3	21.13	29.04	39.44	46.74	53.58	53.05	47	39.64	27.14	16.46	12.27	33.85
15-16	14.13	22.49	30.96	42.07	49.96	57.51	57.1	50.25	41.66	28.3	17.07	12.85	36.01
16-17	14.6	23.1	31.81	43.29	51.58	59.59	59.27	51.73	42.42	28.75	17.41	13.26	37.18
17-18	15.03	23.49	32.23	43.79	52.21	60.42	60.08	52.2	42.77				37.77
18-19					52.53	60.76	60.4	52.46					38.1

The difference between the minimum values (*Min*) and the percentile, P_5, is very high, and is more remarkable in summer time around solar noon, which suggest that the minimum values are not representative of the UVB irradiance at the station level and correspond to unusual extreme values, particularly in summer. Similar results have been obtained by Martinez-Lozano et al. [16], Foyo-Moreno et al. [17] and Bilbao et al. [10] for a number of stations in Spain. On the other hand the difference between the maximum, *Max*, and the 95 percentile, P_{95}, is quite small. In July the differences are lower than 4% at both stations. The absolute maximum values of the two stations were 2.295 W m^{-2} for Athalassa and 2.854 W m^{-2} for Larnaca.

Analysis of monthly average hourly UVB irradiance

The daily variation of the average hourly UVB irradiance is shown in figure 6. The figure shows that UVB irradiance fluctuates between 0.469 W m^{-2} in December and 2.091 W m^{-2} in July at solar noon at Athalassa. The values at Larnaca are higher than in Athalassa and they fluctuate between 0.674 W m^{-2} in December and 2.486 W m^{-2} in June at solar noon. A high symmetry is also observed around the months of June or July when the irradiance reaches its maximum, while it decreases in spring and autumn and reaches its minimum in winter months. The results can be explained by taking into account the symmetry relation between the summer and winter solstices.

Two parameters which influence the magnitude of UVB irradiance are the Total Ozone Column (TOC) and the solar zenith angle. Figure

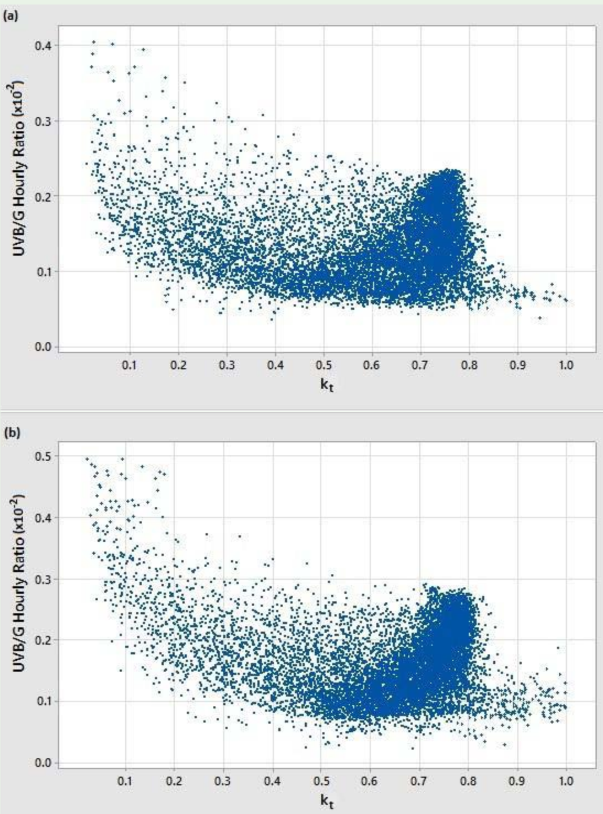

Figure 7: Dependence of hourly *UVB/G* ratio on clearness index (k_t) at a) Athalassa and b) Larnaca.

Table 5: Mean monthly of the hourly *UVB/G* ratio for Athalassa during the periods 2004-2006 and 2013-2015 and Larnaca during the period 2013-2015.

Month	Mean Hourly Ratio UVB/G ($x10^2$)		
	Ath (2004-2006)	Ath (2013-2015)	Lca (2013-2015)
1	0.142	0.109	0.163
2	0.153	0.114	0.159
3	0.158	0.127	0.169
4	0.165	0.13	0.166
5	0.169	0.149	0.179
6	0.171	0.155	0.177
7	0.172	0.162	0.173
8	0.162	0.157	0.168
9	0.186	0.146	0.172
10	0.177	0.132	0.161
11	0.167	0.109	0.15
12	0.139	0.104	0.157
Year	0.163	0.136	0.167

5 shows the annual evolution of the mean daily Total Ozone Column (TOC) and the cosine of the solar zenith angle at midday. The time series of the mean daily values of TOC during the study period were obtained from the satellite instrument MODIS of giovanni application (http://giovanni.sci.gsfc.nasa.gov/giovanni/#service=ArAvTs). The maximum of the TOC is recorded in April (Monthly Mean *TOC*=345 *D.U.*) and the minimum in November (Monthly Mean TOC=285 *D.U.*), while the maximum of the midday hour of the cosine of the zenith angle is observed in June and the minimum in December. Similar results were obtained by Bilbao et al. [37], with the maximum occurring in April in the Northern Hemisphere.

Figure 6 shows that the results are quite in accordance with ozone evolution and the variation of solar zenith angle; comparing March and September, when the solar declination is about zero, it can be seen that the UVB hourly values, due to an ozone decrease, are higher in September than in March.

Analysis of accumulated UVB irradiation

In the studies on the biological effects of UVB irradiation or the availability of solar energy for technological applications, we require the accumulated UVB solar irradiation (kJ m^{-2}) through a period of time. Table 4 shows the accumulated hourly UVB irradiation values for an average day of each month; the last value is the total daily amount.

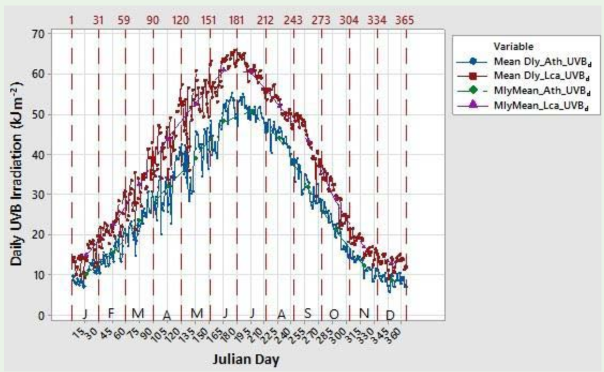

Figure 8: Annual evolution of daily and monthly UVB irradiation values (kJ m^{-2}) at Athalassa and Larnaca, during the period 2013-2015.

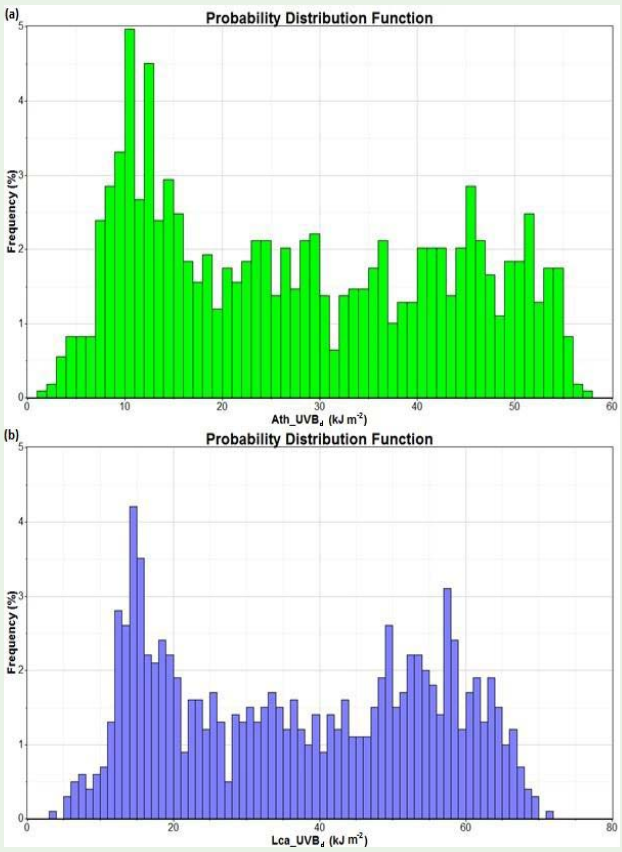

Figure 9: Annual histogram of the frequency distribution of the daily UVB irradiation (kJ m^{-2}) at a) Athalassa and b) Larnaca.

It can be seen that the highest value for UVB irradiation was produced in July, with a daily average of 50.6 kJ m^{-2} for Athalassa, while at Larnaca June and July show almost similar daily average UVB irradiation values around 60 kJ m^{-2}. On the other hand, in December the average energy received was a minimal 8.7 kJ m^{-2} at Athalassa and 13.3 kJ m^{-2} at Larnaca. The accumulated irradiation received in an average year is 10.27 MJ m^{-2} for Athalassa and 13.49 MJ m^{-2} for Larnaca. The values are much higher than those obtained in Valladolid in central Spain (7.04 MJ m^{-2}) [10]. It has to be noted that the station of Valladolid is about 6° higher in latitude than the stations in Cyprus.

Analysis of hourly UVB/G ratio

The increase of *UVB/G* ratio with the cloud cover is significantly higher for low solar elevation. The monthly mean of the hourly *UVB/G* ratio is given in Table 5. For comparison the respective values for Athalassa during the period 2004-2006 are also given [15]. The UVB data during the period 2004-2006 were measured with Skye Instruments Sensors SKU-430. Generally, the values during the period 2004-2006 are higher than those during the period 2013-2015. Furthermore, the values at Athalassa during the period 2004-2006 are approximately similar to those at Larnaca.

Figure 7 shows the dependence of *UVB/G* ratio with the clearness index. The graph shows that for high values of k_t (low cloud cover), a light decrease in the value of *UVB/G* ratio can be observed. On the other hand, when k_t decreases, an increase in *UVB/G* ratio can be observed. So, it can be deduced that UVB hemispherical transmittance is less affected by clouds than the global hemispherical transmittance. Therefore, the presence of clouds reduces less the component UVB than the global solar radiation, due to the strong absorption of water in the near infrared spectrum. Similar results were obtained in Spain by Bilbao et al. [26], but for the total UV irradiance.

Table 6: Statistical estimators of the daily UVB irradiation values (kJ m^{-2}) at a) Athalassa and b) Larnaca, during the period 2013-2015.

a) Athalassa

Month	N	Mean	StDev	CoefVar	Min	Q1	Median	Q3	Max	IQR	Skewness	Kurtosis	P_5	P_{95}
1	93	9.95	2.98	29.95	2.195	7.496	10.205	12.514	14.929	5.018	-0.37	-0.73	4.467	14.131
2	84	15.637	4.198	26.85	6.806	13.279	15.494	18.235	25.195	4.955	0.04	-0.33	8.002	22.964
3	93	23.388	6.058	25.9	3.376	19.574	23.771	28.147	35.116	8.573	-0.44	0.4	11.931	33.894
4	90	31.842	7.569	23.77	15.176	26.851	32.326	36.949	46.22	10.098	-0.32	-0.47	16.835	43.826
5	90	38.868	8.984	23.11	8.011	34.933	41.111	45.326	51.601	10.392	-1.33	1.88	20.152	49.195
6	89	47.973	6.561	13.68	28.364	43.439	49.752	53.123	57.08	9.684	-0.94	0.38	34.46	55.645
7	92	50.586	3.387	6.7	37.231	49.243	51.081	53.154	56.539	3.911	-1.11	1.98	43.425	55.01
8	93	43.767	3.804	8.69	34.482	41.377	44.276	46.217	51.461	4.841	-0.27	-0.18	36.252	50.53
9	90	31.662	5.324	16.82	15.265	28.264	32.436	35.938	42.519	7.673	-0.57	0.17	21.695	38.983
10	93	21.119	4.854	22.99	8.474	17.912	21.824	24.708	29.125	6.796	-0.45	-0.34	12.421	28.314
11	89	12.314	2.496	20.27	4.139	10.915	12.208	14.008	17.366	3.093	-0.26	0.66	7.848	19.663
12	91	8.709	2.314	26.56	1.884	7.908	9.219	10.433	12.377	2.525	-1.16	0.74	3.684	11.189
Year	1087	28.035	15.288	54.53	1.884	13.34	26.394	42.219	57.08	28.879	0.2	-1.31	7.678	52.697

b) Larnaca

Month	N	Mean	StDev	CoefVar	Min	Q1	Median	Q3	Max	IQR	Skewness	Kurtosis	P_5	P_{95}
1	62	14.682	3.629	24.72	5.428	12.753	14.822	17.72	19.893	4.967	-0.8	0.16	6.826	19.554
2	66	22.963	5.412	23.57	9.555	19.357	22.74	27.421	33.13	8.064	-0.14	-0.33	12.753	31.683
3	93	32.105	7.9	24.61	6.999	27.339	33.039	37.722	47.648	10.383	-0.56	0.45	16.604	44.65
4	90	43.632	9.298	21.31	18.747	38.859	44.555	49.666	57.905	10.807	-0.86	0.37	22.957	55.957
5	90	52.38	9.54	18.22	11.98	49.74	53.41	58.65	64.97	8.92	-1.96	5.45	34.857	62.787
6	89	60.729	5.479	9.02	48.708	56.5	61.16	65.466	71.031	8.966	-0.31	-0.9	50.741	68.622
7	93	60.365	4.479	7.42	44.885	57.424	60.82	63.484	69.853	6.06	-0.52	0.68	52.352	67.091
8	69	52.222	3.848	7.37	43.696	49.091	52.133	55.008	59.674	5.917	0.14	-0.63	46.163	59.123
9	69	42.456	5.887	13.87	21.048	39.057	42.41	47.358	51.566	8.301	-0.75	1.12	32.462	50.321
10	93	28.727	5.97	20.78	13.476	24.909	29.648	33.054	39.219	8.144	-0.48	-0.27	17.709	36.827
11	90	16.934	3.355	19.81	7.611	14.781	16.863	19.192	23.508	4.411	-0.15	-0.1	11.226	22.449
12	93	12.885	2.802	21.75	3.952	11.793	13.52	14.942	16.751	3.149	-1.18	1.01	6.489	16.081
Year	997	37.109	18.038	48.61	3.952	19.255	36.768	53.543	71.031	34.288	0.03	-1.37	12.216	64.248

Analysis of UVB daily time series

Daily and monthly average daily UVB irradiation values have been calculated and Figure 8 shows the results for both stations. The daily values present a greater fluctuation in spring season. It can be seen that the variation of the monthly mean values (continuous smooth line) is quite regular, with the maximum values taking place in June and July and the minimum in December. Daily UVB increases in spring to summer with a slope which is smaller than the decrease in autumn. The different slopes can be explained by the total ozone effects. During the summer months, when Solar Zenith Angle (SZA) leads to high UVB irradiance, the *TOC* is declining (Figure 5); this effect drives the maximum levels from June to July.

Table 6 shows the statistical characteristics of daily UVB data for all-sky conditions. The median values are mainly higher than the average ones and the maximum of the standard deviation occurs in May; the coefficient of variation shows the lowest values in the summer months, which means that the highest stability is observed in these months. The differences between the minimum, (*Min*), and the percentile, P_5 are quite high, and therefore, the minimum values correspond to unusual extreme values. On the other hand, the differences between the maximum, (*Max*), and the percentile P_{95} are small. The observed daily maximum is occurred in June at both stations (57 kJ m^{-2} at Athalassa and 71 kJ m^{-2} at Larnaca).

Table 7 shows the monthly average daily values of UVB and Global irradiation at Athalassa during two different periods of measurements with 10 years difference [15]. The Table shows that during the recent period, the mean daily UVB irradiation is higher during the summer months (June-August) in comparison with the previous decade's values. During the rest of the year the mean daily UVB irradiation was lower in the recent decade than the previous one. On the other hand, the mean daily global irradiation was almost similar or slightly higher during the summer months in the recent decade than the previous one. During the rest of the year it was generally higher in the recent decade. As a result the ratios of UVB/G are higher in the summer months during the recent decade than those in the previous decade. However, the yearly average ratios of the two periods are almost similar (0.00158 in the first period compared to 0.00151 in the recent period). Comparing to Larnaca, it is shown that both UVB and global radiation are much higher than Athalassa.

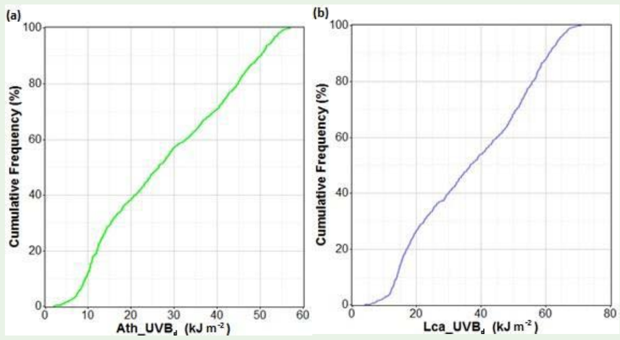

Figure 10: Annual cumulative frequency distribution of daily UVB irradiation at a) Athalassa and b) Larnaca.

Frequency of daily UVB irradiation

The annual histogram of the frequency distribution (*PDF*) of the daily UVB irradiation of both stations is displayed in figure 9, while the cumulative frequency distribution of the same variables is shown in Figure 10. The graphs of *PDF* show similarities with the highest frequencies occurring at around 10 kJ m^{-2} of UVB irradiation. Figure 10, indicates that in 70% of the of the year, the daily sums of UVB irradiation at Athalassa are below 40 kJ m^{-2}, while at Larnaca for the same value the probability is about 55%. It can be also estimated that about 30% of the days of the year have values of daily sum within the range from 40 to 60 kJ m^{-2} at both stations.

Relationship between UVB and other radiation components

It can be useful to estimate UVB irradiance based on the UVA and global irradiance ranges. The correlation between the data have been analysed by assuming relations of the following forms:

$$Y = aX^b \quad (2)$$

$$Y = c + dX + eX^2 \quad (3)$$

Table 7: Average daily UVB and Global irradiation (kJ m^{-2}) and monthly mean ratio UVB/G for two different periods for Athalassa (2004-2006 & 2013-2015) and Larnaca (2013-2015).

Month	Mean Daily UVB irradiation (kJ m^{-2})			Mean Daily Global Solar Irradiation (kJ m^{-2})			Mean Daily Ratio UVB/G (x10^2)		
	Ath (2004-2006)	Ath (2013-2015)	Lca (2013-2015)	Ath (2004-2006)	Ath (2013-2015)	Lca (2013-2015)	Ath (2004-2006)	Ath (2013-2015)	Lca (2013-2015)
1	11.0	9.95	14.682	8500	9358	10012	0.129	0.106	0.147
2	16.0	15.637	22.963	11400	13267	14345	0.14	0.118	0.16
3	26.0	23.388	32.105	17000	17535	18573	0.153	0.133	0.173
4	34.0	31.842	43.632	21300	22273	23921	0.16	0.143	0.182
5	41.0	38.868	52.38	25500	24053	26383	0.161	0.162	0.199
6	45.3	47.973	60.729	27600	27780	29527	0.164	0.173	0.206
7	44.8	50.586	60.365	27000	27961	29261	0.166	0.181	0.206
8	38.0	43.767	52.222	25000	24913	26300	0.152	0.176	0.199
9	35.5	31.662	42.456	20000	20088	21679	0.178	0.158	0.196
10	24.6	21.119	28.727	14400	15511	16723	0.171	0.136	0.172
11	16.6	12.314	16.934	10700	11367	11449	0.155	0.108	0.148
12	9.6	8.709	12.885	8100	8784	9439	0.119	0.099	0.137
Year	28.5	28.035	37.109	18000	18529	19926	0.158	0.151	0.186

Table 8a: Relationships between hourly UVB irradiance (W m^{-2}) and UVA and global (*G*) irradiance (W m^{-2}) at both stations.

Variable y	Variable x	Equation	R^2 / S
UVB_Ath	UVA_Ath	$y = 4.30*10^{-3}x^{1.51}$	S=0.075
UVB_Lca	UVA_Lca	$y = 4.39*10^{-3}x^{1.49}$	S=0.086
UVB_Ath	UVA_Ath	$y = -0.0025 + 0.0127x + 0.00039x^2$	R^2=0.98
UVB_Lca	UVA_Lca	$y = 0.01196 + 0.0125x + 0.00034x^2$	R^2=0.99
UVB_Ath	G_Ath	$y = 1.49*10^{-5}x^{1.72}$	S=0.139
UVB_Lca	G_Lca	$y = 3.15*10^{-5}x^{1.63}$	S=0.148

Table 8b: Relationships between daily *UVBd* irradiation (kJ m^{-2}) and *UVAd* (kJ m^{-2}) and Global (G_d) (MJ m^{-2}) radiation at both stations.

Variable y	Variable x	Equation	R^2 /S
UVBdAth	UVAd_Ath	$y = 0.0020x^{1.363}$	S=2.069
UVBd_Lca	UVAd_Lca	$y = 0.0032x^{1.298}$	S=2.327
UVBd_Ath	UVAd_Ath	$y = -1.040 + 0.018x + 0.000007x^2$	R^2=0.98
UVBd_Lca	UVAd_Lca	$y = 0.302 + 0.018x + 0.000006x^2$	R^2=0.98
UVBdAth	Gd_Ath	$y = 0.366x^{1.464}$	S=3.227
UVBdLca	Gd_Lca	$y = 0.692x^{1.317}$	S=3.378

Table 8 shows the values of the fit parameters for Eqns. (2) and (3) as well as the coefficient of determination, R^2, for the hourly (W m^{-2}) and daily values (kJ m^{-2}) for both stations. The characteristic of these relationships is that the coefficients of determination are close to 1. For the model of the Eq. (2) the fit of the result is given by the parameter *S* which is the standard error of the regression. *S* is measured in the units of the response variable and represents the standard distance the data values fall within the regression line, or the standard deviation of the residuals. For a given study, the better the equation predicts the response, the lower the value of *S*. From the Table 8a, it is indicated that the results were more satisfactory for estimating UVB from the irradiance values in the UVA range, rather than from the global irradiance, although they continued to be acceptable in the latter case. Similar results were obtained for the estimation of the daily values of UVB (Table 8b). The correlation between UVB and global radiation is better described via a quadratic equation. Jacovides et al. [15] using data from Athalassa during the period 2004-2006 arrived into a similar conclusion. Generally, the constants of the equations of the two stations are comparable.

The relationships of the UVB variables between the two stations are shown below. The coefficient of determination is high for both relations.

Hourly data (W m^{-2}):

$$UVB\_Ath = -0.00666 + 0.7753 UVB\_Lca \quad R^2 = 0.93 \quad (4)$$

Daily data (kJ m^{-2}):

$$UVB_d\_Ath = -2.425 + 0.832 UVB_d\_Lca \quad R^2 = 0.95 \quad (5)$$

It is also interesting to know the statistics of the daily UVB radiation obtained from different daily global radiation thresholds, since most of the stations measure global radiation. Table 9 presents the results of the above classification. At Athalassa, the most frequent cases occurred in the bins of 10-12 (MJ m^{-2}) of daily global irradiation following by the bins of 26-28 and 28-30 (MJ m^{-2}). At Larnaca, the values of both global and UVB irradiation are higher and the most frequent cases occurred in the bins of 12-14 (MJ m^{-2}) of daily global irradiation following by the bins of 26-28 and 28-30 (MJ m^{-2}). The mean and the median values of UVB irradiation are almost similar at both stations. It is estimated that UVB irradiation is about 0.16% of the global irradiation at Athalassa (inland location) and about 0.20% at Larnaca (coastal location).

Attenuation of the UVB radiation

In order to assess the attenuation of UVB solar radiation we have estimated the potential UVB irradiation which is defined as the irradiation when the clearness index (K_T) is above 0.65, i.e., a clear day. The daily extratrrestrial (UVB_0) irradiation is estimated from the following equation:

$$UVB_0 = (24/\pi)\varepsilon G_{scUVB}[\sin\phi \sin\delta((\pi\omega_s)/180) + \cos\phi\cos\delta\sin\omega_s] \quad (6)$$

Where ε is the eccentricity, φ is the latitude, δ is the solar declination, ω_s is the sunset hour angle and G_{scUVB}=18.67 W m^{-2}, which was obtained from Gueymard [47].

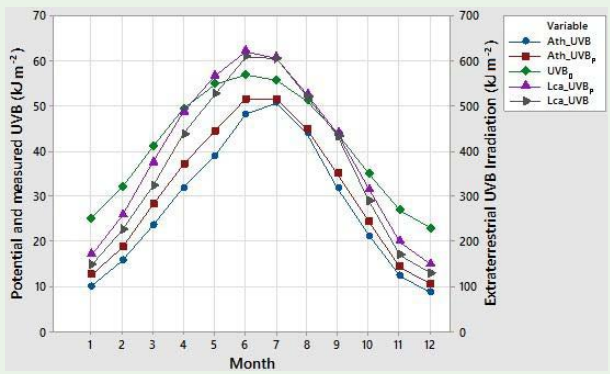

Figure 11: Annual variation of monthly mean values of daily extraterrestrial (UVB_0), potential (UVB_p) and measured UVB irradiation at Athalassa and Larnaca.

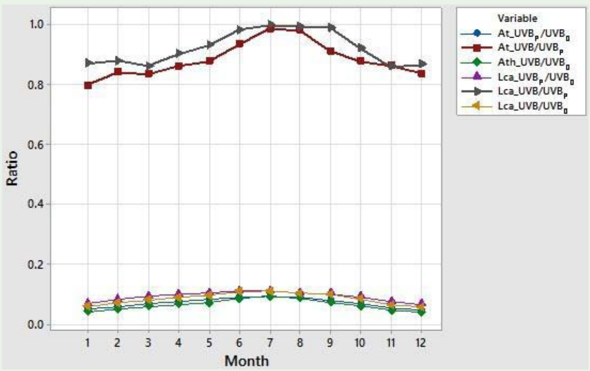

Figure 12: Monthly mean values of the ratios UVB/UVB_p, UVB_p/UVB_0 and UVB/UVB_0 for each station.

Figure 11 shows the monthly average daily values of extraterrestrial (UVB_0), the potential (UVB_p) and measured UVB irradiation for both stations. The graph shows that both UVB and UVB_p at Larnaca are higher than the respective values at Athalassa. The maximum of the said variables is recorded in June at Larnaca, but at Athalassa UVB is higher in July, while the maximum of UVB_p is recorded in June and July. The difference between the UVB_p and UVB measured values is greater in the spring and winter time, while during the summer the difference is small. This is attributed to the fact that during the summer almost all days are clear [38].

From the monthly mean values of UVB potential, extraterrestrial and measured radiation, the ratios between these variables were estimated. The ratio UVB/UVB_p represents information about the percentage of energy which, on the average, is transmitted by the atmosphere and may be considered as the atmospheric transparency under average conditions, i.e., including hydrometeors and aerosols. The ratio of UVB potential to UVB extraterrestrial, UVB_p/UVB_0, gives information about the atmospheric transparency on clear days, i.e, without clouds but with aerosols, though in low proportion. The ratio of UVB/UVB_p, represents the observed UVB irradiation fraction which corresponds to cloud-free sky, i.e., this attenuation is due to cloudiness and aerosols.

Figure 12 shows the monthly mean of the above ratios for each station. The greatest variability is shown in the ratio of UVB/UVB_p. The other ratios show similar variation, but the values are very low. The evolution of these ratios increases from spring to summer and decreases from summer to winter. The maximum of these ratios in the summer is about 9% at Athalassa and about 11% at Larnaca (Figure 13).

Table 9: Statistics of daily UVB irradiation (kJ m^{-2}) based on various thresholds of daily global radiation (MJ m^{-2}) for the period of measurements, for a) Athalassa and b) Larnaca.

a) Athalassa

Ath-Daily Global Irradiation Bin Endpoints (MJ m^{-2})		Ath-Daily UVB irradiation (kJ m^{-2})					
Lower	Upper	Occurrences	Mean	Median	Min	Max	Std. Dev.
0	2	4	2.39	2.2	1.88	3.38	0.67
2	4	14	4.46	4.21	3.46	8.04	1.16
4	6	25	6.65	6.35	4.78	10.03	1.27
6	8	41	8.25	7.88	5.75	11.29	1.19
8	10	59	10.07	9.74	7.67	15.3	1.55
10	12	119	12.32	11.81	8.47	20.24	2.52
12	14	90	14.78	14.16	11	26.39	2.81
14	16	72	18.76	18.54	13.49	26.7	3.31
16	18	81	23.04	22.66	18.12	33.37	2.98
18	20	64	26.73	26.82	17.89	35.36	3.06
20	22	76	31.68	31.45	23.19	41.58	4.17
22	24	79	36.4	36.69	27.64	46.05	4.69
24	26	91	41	41.91	29.07	48.06	4.48
26	28	110	45.9	46.64	32.92	52.41	4.16
28	30	106	50.8	51.51	36.96	55.91	3.65
30	32	18	54	54.43	47.52	57.08	2.46

b) Larnaca

Lca-Daily Global Irradiation Bin Endpoints (MJ m^{-2})		Lca-Daily UVB irradiation (kJ m^{-2})					
Lower	Upper	Occurrences	Mean	Median	Min	Max	Std. Dev.
0	2	3	4.87	5.22	3.95	5.43	0.8
2	4	12	7.13	7.25	5.61	9.28	1.02
4	6	11	9.97	9.36	7.47	14.48	2.48
6	8	37	12.21	12.06	9.76	19.32	1.85
8	10	51	13.93	13.59	11.47	19.31	1.63
10	12	88	16.1	15.47	12.25	25.4	2.48
12	14	94	19.15	18.57	12.4	31.38	3.22
14	16	60	24.07	23.79	18.48	31.75	3.18
16	18	56	28.42	28.7	22.2	38.4	3.68
18	20	62	33.65	33.03	25.19	42.59	3.62
20	22	71	37.55	37.01	29.23	46.58	3.45
22	24	57	43.17	43.41	33.96	53.16	4.32
24	26	76	48.3	49.02	39.03	55.79	3.32
26	28	100	52.89	53.17	41.62	62.18	4.29
28	30	136	58.72	58.6	48.73	67.17	4.3
30	32	82	62.85	63.76	54.3	71.03	4.09
32	34	1	62.04	62.04	62.04	62.04	0

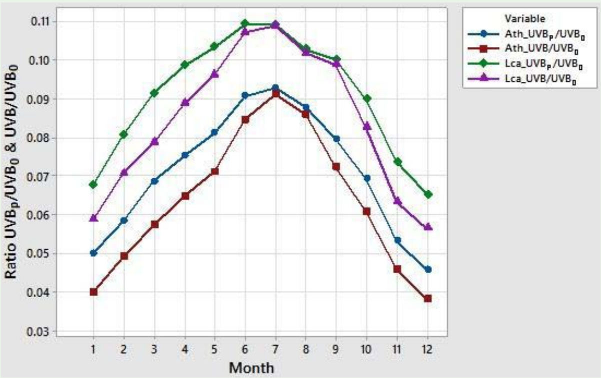

Figure 13: Monthly mean values of the ratios UVB_p/UVB_0 and UVB/UVB_0 for each station.

Relationships between hemispherical transmittances

In this section the relationships between the clearness index or global hemispherical transmittance (k_t) and the UVB hemispherical transmittance (k_{tUVB}) will be examined. The clearness index is defined as: $k_t = G / G_0$, G being the measured global irradiance and G_0 the extraterrestrial solar irradiance, both measured on horizontal surface and for the same interval of time [2]. In the same way the UVB hemispherical transmittance (k_{tUVB}) is defined as: $k_{tUVB} = UVB / UVB_0$, where UVB is the measured variable and UVB_0 is the extraterrestrial UVB irradiance, both measured on a horizontal surface during the same time interval. The small 'k' refers to hourly values, while the capital letter 'K' denotes daily values.

Figure 14 shows the histograms with the hourly values of k_t. Most of the data are concentrated in the 0.7-0.8 range at both stations. The clearness index is mostly affected by the presence of clouds. Figure 15 shows the histograms with the hourly values of k_{tUVB}. Most of the data are concentrated in the 0.04-0.06 range at both stations.

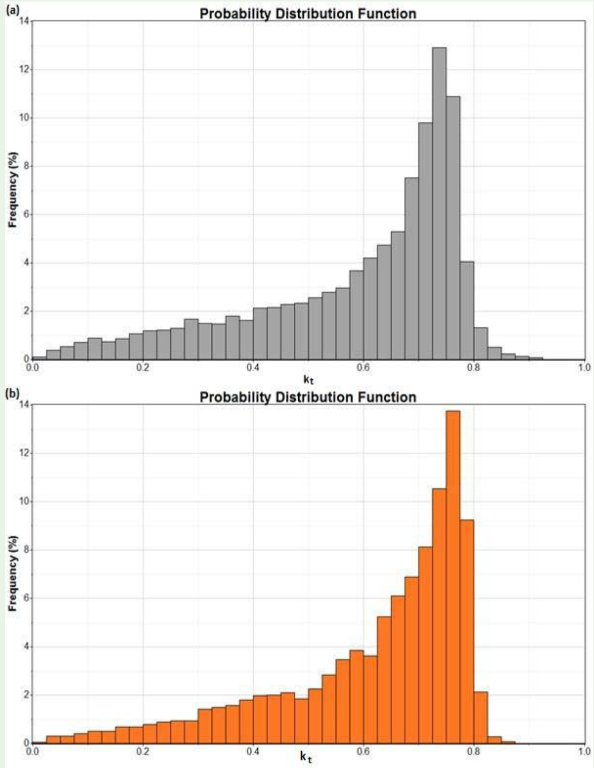

Figure 14: Frequency distribution of hourly clearness index (k_t) at a) Athalassa and b) Larnaca.

The above results suggest that relationships can be established between the indexes k_t and k_{tUVB}. Three different models were examined. Firstly, a linear fit was applied, without intercept of the form: $k_{tUVB} = ak_t$. Secondly, a quadratic equation was tested and thirdly a model of the form of Eqn. (2). The above models were

Table 10a: Relationship between hourly transmittance k_{tUVB} of UVB irradiance and the clearness index (k_t) of global irradiance (Wm^{-2}) at both stations.

Variable y	*Variable x*	*Equation*	R^2 / S
ktUVB_Ath	kt_Ath	$y = 0.101x$	0.88
ktUVB_Lca	kt_Lca	$y = 0.125x$	0.89
ktUVB_Ath	kt_Ath	$y = 0.0099 + 0.041x + 0.0664x^2$	0.42
ktUVB_Lca	kt_Lca	$y = 0.029 - 0.024x + 0.149x^2$	0.40
ktUVB_Ath	kt_Ath	$y = 0.108x^{1.159}$	S=0.023
ktUVB_Lca	kt_Lca	$y = 0.137x^{1.254}$	S=0.028

Table 10b: Relationships between the daily transmittance (K_{TUVB}) and the daily transmittance (K_T) at both stations.

Variable y	*Variable x*	*Equation*	R^2 /S
KTUVB_Ath	KT_Ath	$y = 0.091x$	0.97
KTUVB_Lca	KT_Lca	$y = 0.131x$	0.97
KTUVB_Ath	KT_Ath	$y = 0.014 + 0.010x + 0.089x^2$	0.63
KTUVB_Lca	KT_Lca	$y = 00.027 - 0.0013x + 0.136x^2$	0.67
KTUVB_Ath	KT_Ath	$y = 0.1005x^{1.210}$	S=0.010
KTUVB_Lca	KT_Lca	$y = 0.141x^{1.187}$	S=0.013

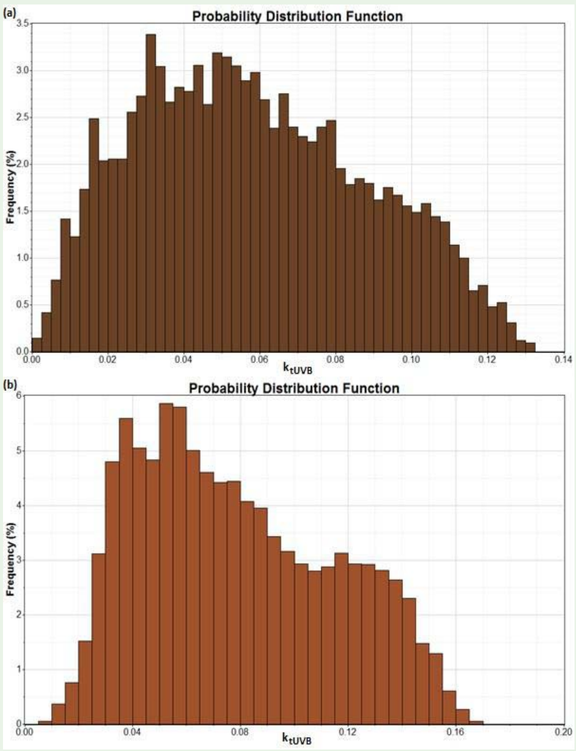

Figure 15: Frequency distribution of hourly UVB hemispherical transmittance (k_{tUVB}) at a) Athalassa and b) Larnaca.

applied for both the hourly and daily values of the said transmittances (Table 10). As it is indicated from the constant of the linear fit, the hemispherical transmittance k_{tUVB} is approximately 10 % of the hemispherical transmittance for the whole spectrum (k_t). In the case of the linear regression, the coefficient of determination (R^2) is close to 0.9 for the hourly values and 0.97 for the daily values, suggesting that the linear fit is better than the other models. The standard error of the regression (S) of the third model is also low which suggests that the model could be also used for the prediction of the k_{tUVB} transmittance. Generally, the values of the constants of the three models of the two stations are comparable.

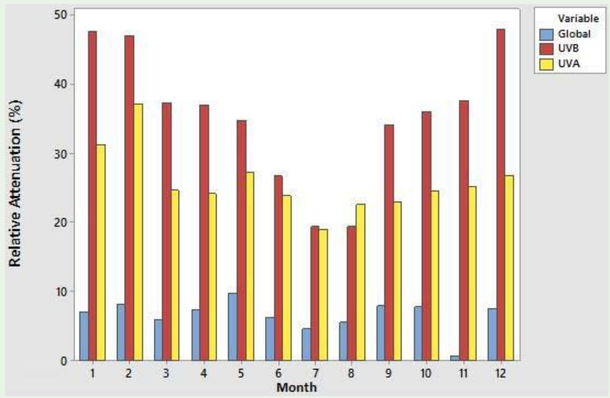

Figure 16: Relative attenuation of solar global, UVB and UVA radiation for Athalassa and Larnaca.

Inter-comparison of the two sites

The inter-comparison of the broad-band solar radiation intensity measurements at both sites are reported in Table 11 for the global, UVB, and UVA radiation. The solar radiation intensities are reported as monthly average daily values, the number of days of each variable for the period of measurements and the relative attenuation reported for each one, which is defined as:

$$RelativeAttenuation(\%) = ((X_{Lca} - X_{Ath}) / X_{Ath})*100 \quad (7)$$

where X referes the type of solar radiation, i.e., either global, UVB or UVA. The subscripts refer to the two sites.

As indicated in Table 11, the magnitudes of the monthly average daily values of the three types of solar radiation components are higher at Larnaca than at Athalassa. Generally, the percentages of relative attenuation are lower during the summer period for all the three variables. The magnitudes of the monthly average daily solar global radiation intensity at the two sites are very similar. The % relative attenuation is < 10% for all months. The differences in altitude between the two stations are not significant and therefore the

Table 11: Monthly average daily solar global, UVB and UVA at Athalassa and Larnaca and their relative differences.

	Ath (Gd)		Lca (Gd)			Ath (UVBd)		Lca (UVBd)			Ath (UVAd)		Lca (UVAd)		
Month	N	Mean MJ/m²	N	Mean MJ/m²	% Relative attenuation	N	Mean kJ/m²	N	Mean kJ/m²	% Relative attenuation	N	Mean kJ/m²	N	Mean kJ/m²	% Relative attenuation
1	93	9.36	92	10.01	6.99	93	9.95	62	14.68	47.56	93	515.4	31	676.1	31.18
2	84	13.27	66	14.35	8.13	84	15.64	66	22.96	46.85	84	718.1	38	984.1	37.04
3	93	17.54	93	18.57	5.92	93	23.39	93	32.11	37.27	93	973.2	62	1212.5	24.59
4	90	22.27	90	23.92	7.4	90	31.84	90	43.63	37.03	90	1249.7	54	1551	24.11
5	77	24.05	93	26.38	9.69	90	38.87	90	52.38	34.76	90	1407.6	49	1790.9	27.23
6	82	27.78	90	29.53	6.29	89	47.97	89	60.73	26.59	89	1612.6	30	1995.8	23.76
7	92	27.96	93	29.26	4.65	92	50.59	93	60.37	19.33	92	1650.9	77	1962.8	18.89
8	93	24.91	93	26.3	5.57	93	43.77	69	52.22	19.32	93	1467.9	66	1798.1	22.49
9	84	20.09	90	21.68	7.92	90	31.66	69	42.46	34.09	90	1140.2	35	1400.3	22.81
10	93	15.51	93	16.72	7.81	93	21.12	93	28.73	36.02	93	869.7	74	1082.8	24.5
11	78	11.37	90	11.45	0.72	89	12.31	90	16.93	37.52	89	595.7	82	745.2	25.1
12	91	8.78	93	9.44	7.46	91	8.71	93	12.89	47.95	91	467.6	62	592.3	26.67
Year	1050	18.53	1076	19.93	7.54	1087	28.04	997	37.11	32.37	1087	1056.9	660	1305.6	23.53

Table 12: Inter-comparison of the two sites with respect to global and UVB radiation.

Variable	Athalassa	Larnaca
Location	inland	coastal
Annual daily average global irradiation (Gd) (MJ/m^2)	18.53	19.93
Annual total global irradiation (MJ/m^2)	6835	7183
Annual daily average UVB irradiation (UVBd) (kJ/m^2)	28.04	37.11
Annual total UVB irradiation (MJ/m^2)	10.27	13.49
Accumulated daily UVB irradiation in July (kJ/m^2)	50.59	60.4
Accumulated daily UVB irradiation in December (kJ/m^2)	8.71	13.26
Mean annual daily ratio of UVB/G	0.00151	0.00186
Maximum Hourly Average UVB irradiance in July (W/m^2)	2.09	2.48
Maximum Hourly Average UVB irradiance in December (W/m^2)	0.47	0.67
Mean annual Ratio of daily UVB/UVB_p	0.92	0.88

daily values are almost similar. However, the percentage of relative attenuation of UVB is higher than that of UVA since the attenuation is inversely proportional to the wavelength and therefore greater for the shorter UVB wavelengths. The high values of relative attenuation of the UVA radiation could be also attributed to the fact that long periods of missing data were detected in the time series of UVA at Larnaca. The percent relative attenuation is also presented graphically for the three solar radiation types in Figure 16.

The summary of the inter-comparison of the two sites is presented in Table 12.

Conclusion

Measured data at 10 min intervals, obtained by UV Kipp & Zonen radiometers installed at two locations in Cyprus, one at Athalassa (inland location) and the other at Larnaca (coastal location) during the period January 2013 and December 2015, have been used to define the statistical characteristics of both hourly UVB irradiance and daily UVB irradiation values.

Large fluctuations in the spring months and November are mainly due to unstable meteorological conditions during the transition from cold to warm weather and vice versa. During summer the daily UVB radiation exceeds the value of 70 kJ m^{-2} at Larnaca and 55 kJ m^{-2} at Athalassa, while during the winter season the lowest is about 5 kJ m^{-2} at both stations. Slightly lower values were recorded in the year 2015 at both stations which can be attributed to the higher amounts of aerosols in the atmosphere. The year 2015 is characterized as an extremely dry year with more frequent dust episodes over the island (dust from the deserts of Middle East and Sahara), increasing therefore the aerosols in the atmosphere which affect the absorption of the UVB radiation. The accumulated UVB irradiation received in an average year is 10.27 MJ m^{-2} for Athalassa and 13.49 MJ m^{-2} for Larnaca, which are much higher than the respective value in Valladolid (Spain) (7.04 MJ m^{-2}).

The UVB variability has been studied by means of the coefficient of variation (CV). It was demonstrated that the CVs in July are low during the midday (5-7%) at both stations, indicating a high stability along these hours in summer.

Regarding the hourly values, UVB irradiance fluctuates between 0.469 W m^{-2} in December and 2.091 W m^{-2} in July at solar noon at Athalassa. The values at Larnaca are slightly higher than in Athalassa and they fluctuate between 0.674 Wm^{-2} in December and 2.486 W m^{-2} in June at solar noon.

With respect to the estimation of UVB irradiance, it is indicated that the results were more satisfactory for estimating UVB from the irradiance values in the UVA range rather than from the global irradiance, although they continued to be acceptable in the latter case. Similar results were obtained for the estimation of the daily values of UVB. Generally, the constants of the equations of the two stations are comparable.

It is estimated that UVB irradiation is about 0.16% of the global irradiation at Athalassa (inland location) and about 0.20% at Larnaca (coastal location).

The difference between the potential UVB (UVB_p) and the measured UVB values is greater in the spring and winter time, while during the summer the difference is small. This is attributed to the fact that during the summer almost all days are clear.

Three different models were implemented to estimate the UVB transmittance. Firstly, a linear fit was adopted, without intercept of the form: $k_{tUVB} = ak_t$. Secondly, a quadratic equation was tested and thirdly a model based of the form of Eqn. (2). The above models were applied to both the hourly and daily data. As it is indicated from the constant of the linear fit, the hemispherical transmittance k_{tUVB} is approximately 10 % of the hemispherical transmittance for the whole spectrum (k_t). In the case of the linear regression, the coefficient of determination (R^2) is close to 0.9 for the hourly values and 0.97 for the daily values, suggesting that the linear fit is better than the other models.

For high values of k_t (low cloud cover), a light decrease in the value of *UVB/G* ratio was recorded. On the other hand, when k_t decreases (i.e., during partly cloudy and cloudy conditions), an increase in *UVB/G* ratio can be observed. So, it can be deduced that UVB hemispherical transmittance is less affected by clouds than the global hemispherical transmittance. Therefore, the presence of clouds reduces less the component UVB than the global solar radiation, due to the strong absorption of water in the near infrared spectral region.

We conclude, based upon the above analysis, that the two sites in Cyprus are characterised by relatively high average-daily irradiation rates and a relatively high frequency of clear days. Comparing the two sites we may observe that Larnaca has slightly higher rates of global and UVB radiation than Athalassa.

The radiation climate of the two sites will be further examined by elaborating in a similar approach for the other UV solar radiation components (UV erythemal (*UVER*), UV Index (*UVI*), *UVA* and

UV total radiation) as well as the long wave radiation. Then the net radiation balance will be estimated and the climate characteristics will be assessed at a given site. These however will be the subject of other papers.

Nomenclature

A_s Skewness coefficient

CDF Cumulative probability density function

CV Coefficient of variation (%)

D.U. Dobson unit (thickness of ozone in units of 10 μm)

G Global solar irradiance [Wm^{-2}]

G_0 Extra terrestrial irradiance [Wm^{-2}]

G_{0d} Daily extra terrestrial irradiation (ETR) [MJ m^{-2}]

G_d Daily global irradiation [MJ m^{-2}]

G_{sc} Solar constant [1367 Wm^{-2}]

G_{scUVB} Solar constant of UVB irradiance [18.67 Wm^{-2}]

IQR Interquartile range

K Kurtosis

k_t Hourly clearness index ($k_t = G / G_0$)

k_{tUVB} Hourly UVB transmittance ($k_{tUVB} = UVB / UVB_0$)

K_T Daily clearness index ($K_T = G_d / G_{0d}$)

Max Maximum

Min Minimum

N Non missing observations

N^* Missing observations

n Julian day number (1..365)

P_5 Percentile 5%

P_{95} Percentile 95%

PDF Probability density function

Q1 First Quartile

Q3 Third Quartile

S Standard error of the regression or standard deviation of the residuals

StDev Standard deviation

TOC Total Ozone column

UVC Ultraviolet radiation in the range of 100 to 280 nm

UVB UVB irradiance [Wm^{-2}] / UVB irradiation [kJ m^{-2}]

UVB_0 Extraterrestrial UVB irradiance [Wm^{-2}]

UVB_p Potential UVB irradiance [Wm^{-2}]

UVB_d Daily UVB irradiation [kJ m^{-2}]

UVA UVA irradiance [Wm^{-2}] / UVA irradiation [kJ m^{-2}]

UVA_d Daily UVA irradiation [kJ m^{-2}]

UVER UV erythema irradiance [Wm^{-2}] / UV erythema irradiation [kJ m^{-2}]

UVI UV Index

UV UV irradiance [Wm^{-2}] / UV irradiation [kJ m^{-2}] (UV (A+B))

Greek:

θ_z Solar zenith angle (SZA) [degrees]

δ Solar declination [degrees]

ε eccentricity correction

φ Latitude [degrees]

ω_s Sunset hour angle [degrees]

References

1. CIE, 1999. Standardization of the terms UV-A1, UV-A2 and UV-B. Vienna: CIE, Report CIE-134/1.
2. Iqbal M. An Introduction to Solar radiation. Academic Press, 1983; New York.
3. Coldiron B. The UV Index: A weather report for skin. Clin.Dermatol. 1998; 16: 441-446.
4. Diffey B L. The consistency of studies of ultraviolet erythema in normal human skin. Phys. Med. Biol. 1982; 27: 715-720.
5. Fioletov E, McArthur E, Mathews T, Marrett L. On the relationship between erythemal and vitamin D action spectrum weighted ultraviolet radiation. Journal of Photochemistry and Photobiology B: Biology. 2009; 95: 9-16.
6. WMO and UNEP, 2006. Executive Summary: WMO/UNEP Scientific Assessment of Ozone Depletion. Prepared by the Scientific Assessment Panel of the Montreal Protocol on Substances That Deplete the Ozone Layer.
7. Casale G.R, Meloni D, Miano S, Palmieri S, Siani A M. Solar UV-B irradiance and total ozone in Italy: fluctuations and trends. J. Geophys. Res. 2000; 105: 4895-4901.
8. Bartlett L M, Webb A R. Changes in ultraviolet radiation in the 1990s: spectral measurements from Reading, England. J. Geophys. Res. 2000; 105: 4889-4893.
9. Zerefos C, Meleti C, Lambros A. The recent UV variability over south-eastern Europe. Journal of Photochemistry and Photobiology. 1995; 20: 15-19.
10. Bilbao J, Gonzalez P, Miguel A. UV-B climatology in Central Spain. International Journal of Climatology. 2008; 28: 1933-1941.
11. Utrillas M , Marín M , Esteve A, Estellés V, Gandía S, Núnez J, Martinez-Lozano J. Ten years of measured UV Index from the Spanish UVB Radiometric Network. Journal of Photoch and Photob. B: Biology. 2013; 125: 1-7.
12. Kudish A, Lyubankskу V, Evseev E, Ianetz A. Statistical analysis and inter-comparison of the solar UVB, UVA and global radiation for Beer Sheva and Neve Zohar (Dead Sea), Israel. Ther Appl Climatol. 2005; 80: 1-15.
13. Robaa S M. A study of ultraviolet solar radiation at Cairo urban area, Egypt. Solar Energy. 2004; 77: 251-259.
14. Jacovides CP, Assimakopoulos VD, Tymvios F, Theophilou K, Assimakopoulos DN. Solar global UV (280-380 nm) radiation and its relationship with solar global radiation measured on the island of Cyprus. Energy. 2006; 31: 2728-2738.
15. Jacovides C ,Tymvios F, Assimakopoulos D, Kaltsunides N ,Theocharatos G, Tsitouri M. Solar UVB (280-315 nm) and UVA (315-380 nm) radiant fluxes

and their relationships with broadband global radiant flux at an eastern Mediterranean site. Agricultural and Forest Meteorology. 2009; 149: 1188-1200.

16. Martinez-Lozano J, Tena F, Utrillas P. Measurement and analysis of ultraviolet solar irradiation in Valencia, Spain. International Journal of Climatology. 1996; 16: 947-955.
17. Foyo-Moreno I , Vida J, Alados-Arboledas I. Ground-based ultraviolet (290-385 nm) and broadband solar radiation measurements in south-eastern Spain. . International Journal of Climatology. 1998; 18: 1389-1400.
18. Cañada J, Pedrós G, López A , Boscà J. Influence of the clearness index for the whole spectrum and of the relative optical air mass on UV solar irradiance for two locations in the Mediterranean area, Valencia and Córdoba. Journal of Geophysical Research. 2000; 105: 4759-4766.
19. Mantis H T, Repapis C C, Philandras C, Pañiatsos A G, Zerefos C S, Bais A F, Meleti C, Balis D S. A 5-year climatology of solar erythemal ultraviolet in Athens, Greece. International Journal of Climatology. 2000; 20: 1237-1247.
20. Koronakis P, Sfantos G K, Pañiatsos A, Kaldellis J, Garofalakis J, Koronakis J. Interrelations of UV-global/global/diffuse solar irradiance components and UV-global attenuation on air pollution episode days in Athens, Greece Atmospheric Environment. 2002; 36: 3173-3181.
21. Kudish A I, Evseenv E. Statistical relationships between solar UVB and UVA radiation and global radiation measurements at two sites in Israel. International Journal of Climatology. 2000; 20: 759-770.
22. Jacovides C.P, Boland J, Rizou D, Kaltsounides N, Theocharatos G. School Students participation in monitoring solar radiation components: Preliminary results for UVB and UVA solar radiant fluxes. Renewable Energy. 2012; 39: 367-374.
23. Alados I, Mellado J, Ramos F, Alados-Arboledas I. Estimating UV erythemal irradiance by means of neural networks. Journal of Photochemistry and Photobiology. 2004; 80: 351-358.
24. Jacovides C.P, Tymvios F, Boland J, Tsitouri M. Artificial Neural Network models for estimating daily solar global UV, PAR and broadband radiant fluxes in an eastern Mediterranean site. Atmospheric Research. 2015; 152: 138-145.
25. Mateos D, Miguel A, Bilbao J. Empirical models of UV total radiation and cloud effect study. International Journal of Climatology. 2010; 30:1407-1415.
26. Bilbao J, Mateos D , Miguel A. Analysis and cloudiness influence on UV total irradiation. International Journal of Climatology. 2011; 31: 451-460.
27. Koepke P, Bais A, Balis D, Buchwitz M, de Backer H, de Cabo X, Eckert P et al. Comparison of models used for UV index calculations. Photochem. Photobiol. 1998; 67: 657-662.
28. EUR 20611. 2003. UV-B forecasting. Final Report of COST Action 713.
29. EUR 23338. 2008. Modelling solar UV radiation in the past: Comparison of the algorithms and input data. Final Report of COST Action 726.
30. Bilbao J, Miguel A. Contribution to the study of UV-B solar radiation in Central Spain. Renewable Energy. 2013; 53: 79-85.
31. Martinez-Lozano J, Utrillas M , Núnez J , Esteve A, Gómez-Amo J, Estellés V, et al. Measurement and analysis of broadband UVB solar radiation in Spain. Photochemistry and Photobiology. 2012; 88: 1489-1496.
32. Kudish A, Evseev E. UVB irradiance and atmospheric optical depth at the Dead Sea basin, Israel: Measurements and modeling. Renewable Energy. 2012; 48: 344-349.
33. Kudish A , Evseev E. The analysis of solar UVB radiation as a function of solar global radiation, ozone layer thickness and aerosol optical density. Renewable Energy. 2011; 36: 1854-1860.
34. Bilbao J, Miguel A. Estimation of UV-B irradiation from total global solar radiation data in central Spain.Journal of Geophysical Research. 2010; 115: 10.
35. Kudish A. The measurement and analysis of UV radiation and its use in optimizing treatment protocols for photoclimatherapy of psoriasis at the Dead Sea medical spas. Journal of Dead Sea and Arava Research. 2009; 1: 1-13.
36. Salvador P, Bilbao J, Miguel A. Ultraviolet-B solar irradiance, the influence of Ångstrom turbidity, at Central Spain. Journal of Atmospheric and Solar-Terrestrial Physics. 2008; 70: 1643-1650.
37. Bilbao J, Miguel A, Salvador P. UV-B solar irradiance and the influence of total ozone and aerosols at central Spain. In Conference on Visibility, Aerosols and Atmospheric Optics, Viena, September. 2006.
38. Jacovides C P, Kaltsunides N, Hachioannou L &Stefanou L. An assessment of the solar radiation climate of the Cyprus environment. Renewable Energy. 1993; 3: 913-918.
39. Kambezidis C. Typical Meteorological Year for Nicosia. Theory and user guide. 1999.
40. Kalogirou S, Pashiardis S, Pashiardi A., 2016. Statistical analysis and inter-comparison of the global solar radiation at two sites in Cyprus. Renewable Energy. 2016; 101: 1102-1123.
41. World Meteorological Organization. WMO, 1987. Guidelines on the quality control of data from the World Radiometric Network. WCDP-3, WMO/TD-No.258, p 30, WMO, Geneva, Swittzerland.
42. Long C N and Dutton E.G. 2002. Global Network recommended QC tests, V2.0, BSRN Technical Report (http://ezksun3.ethz.ch/bsrn/admin/dokus/qualitycheck.pdf).
43. Long C.N. and Shi Y. An automated quality assessment and control algorithm for surface radiation measurements. The Open Atmospheric Science Journal. 2008; 2: 23-37.
44. Muneer T. Solar Radiation and Daylight models. 2004; 2nd Edition. Oxford: Elsevier.
45. Pashiardis S , Kalogirou S. Quality control of solar shortwave and terrestrial long wave radiation for surface radiation measurements at two sites in Cyprus. Renewable Energy. 2016; 96: 1015-1033.
46. Miguel A, Bilbao J, Aguilar R, Kambezidis H, Negro E. Diffuse solar irradiation model evaluation in the North Mediterranean belt area. Solar Energy. 2001; 70: 143-153.
47. Gueymard C. The sun's total and spectral irradiance for solar energy applications and solar radiation models. Solar Energy. 2004; 76: 423-453.