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Research Article

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

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Abstract

A statistical analysis and inter-comparison of the Ultraviolet Radiation (UVR) at two sites in Cyprus representing two different climate regimes of the island (Athalassa-inland plain vs Larnaca-coastal location) covering the period 2013-2015 is presented. Mean annual and mean monthly daily totals of the UV irradiation and their frequency distribution at both sites are computed and discussed. The total accumulated UV irradiation along an average year reaches 398 MJ m^{-2} at Athalassa and 494 MJ m^{-2} at Larnaca. During summer, the daily UV radiation exceeds the value of 1800 kJ m^{-2} at Athalassa and 2200 kJ m^{-2} at Larnaca. Linear relationships were established between UVR and global solar radiation, with the coefficient of determination close to 1. These relationships indicate that UV irradiation corresponds to 5.9% and 6.8% of the horizontal global solar irradiation at the two sites, respectively. Four models were tested for the estimation of UVR and the best performed models were recalibrated according to the local conditions. Relationships between the clearness index (k_t) and the UV hemispherical transmittance (k_{tUV}) were also established. The annual k_{tUV} is about 71% of k_t. Finally, the dependence of the UV/G ratio values to the solar elevation angle and clearness index was also examined. It can be concluded that the presence of clouds reduces less the UV component rather than the global solar radiation, due to the strong absorption of water in the near infrared spectrum.

Introduction

Solar Ultraviolet Radiation (UV) has received considerable attention in the last decades because it is involved in chemical and biological processes. 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. UV radiation is divided in three parts 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. In the upper atmosphere, UVB irradiance amounts to 1.3% of the solar constant [2]. 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 [3]. Measurements in Italy and England indicate that UVB incidence increased with decreasing ozone amount at fixed solar zenith angles [4-5].

Solar UV radiation has an important influence in terrestrial and marine ecosystems. Severe skin overexposure produces sunburn that causes heat, erythema and other symptoms approximately 16 hours after exposure to natural sunlight [6]. Epidemiological evidence also exists of the direct influence of sunlight over skin cancer in human beings [7-8]. On the other hand, among the benefits 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 [9].

In spite of the important role of UV radiation, few radiometric stations measure systematically UV solar radiation components in the Mediterranean region. A network of UV stations was established in Greece [10], Spain [11-12], Italy [13], Malta [14], Israel [15] and Egypt [16]. In Cyprus, UV radiation is measured currently at two locations: Athalassa (inland) and Larnaca (coastal) [17-18].

The main factors which affect the levels of UV radiation are the solar elevation, cloud cover, stratospheric ozone column and aerosols. Several authors studied the trends of UV radiation levels and measurements of these variables. The solar elevation is related to the optical air mass,

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which is defined as the ratio between the relative optical mass in a given direction and the optical air mass in a vertical direction and is calculated by the expression proposed by Kasten and Young [19] Canada et al. [20] 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. The influence of ozone was reported by Bilbao et al. [21], while the influence of aerosols was studied by Meloni et al. [22-23]. The combined effect of aerosols and ozone was studied by Di Sarra et al. [13]. The relationship between the UV and global solar radiation and its dependence on total ozone column, cloudiness or aerosols was analyzed by Antón et al. [24]. The influence of cloudiness on UV global irradiance was analyzed by Foyo-Moreno et al. [25].

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 [26-27]. Some authors use empirical models which are simpler and more manageable and understandable [28-29]. Martinez-Lozano et al. [30] studied UV irradiance values in Valencia in the period 1991-1994. Foyo-Moreno et al. [31] analyzed UV and global irradiance in Granada. Mantis et al. [32], Koronakis et al. [33], Kudish and Evseev [34], Kudish et al. [35], Jacovides et al. [17-18,36] performed statistical analysis of various components of UV radiation and global irradiances in Athens (Greece), Beer Sheva (Israel) and Athalassa (Cyprus), respectively.

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 [37]. The results of these simulations were also published in the final report of the COST Action 713 [38]. A second COST Action (COST-726) was established later to assess the long term changes and climatology of UV radiation over Europe [39].

An assessment of the solar radiation climate of the Cyprus environment was presented by Jacovides et al in 1993 [40]. Kambezides [41] presented the 'Typical Meteorological Year' for Nicosia. More recently, Kalogirou et al. [42] presented a statistical analysis and inter-comparison of the solar global radiation at two sites in Cyprus using measurements of 21 months at both sites. A statistical analysis of UV erythemal radiation (UVER) was the subject of the study presented by Kalogirou et al (in press) [43].

The aim of this paper is to analyze UVT solar irradiation from measurements obtained from UVB and UVA radiometers. In this study, a statistical analysis has been carried out by calculating various statistical parameters. The analysis was performed on both the hourly UV irradiances and the daily UV irradiation. Moreover, the relationships between UV and global solar irradiation are established and the results are compared with other studies carried out in the Mediterranean region. Furthermore, several empirical models for the estimation of UV radiation were tested. Additionally, the influence of the most important factors of solar elevation and cloudiness has been also studied. Finally, an inter-comparison study between two locations in Cyprus (inland vs coastal) was carried out.

Topogrphy, Climatology, Measurements and Quality Control

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 (35.141° N, 33.396° E, 165 m) and the other one at Larnaca Airport which is near the coast (34.873° N, 33.631° E, 1 m).

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. 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 radiation exceed 18.5 MJ m^{-2} at the two sites, where 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 6835 MJ m^{-2} for Athalassa and 7183 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 90% annually (K_T>0.35) [42].

Measurements and quality control processes

The period for presenting the data in both stations is January 2013until December 2015 (i.e., 3years), when both stations operated simultaneously, so as to allow for comparison of the different variables of solar and terrestrial radiation. Measurements of total 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 70^0 solar zenith angle (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 outdoors against standard references at irregular time intervals during the study period. The errors involved in the radiation measurements are found to be no 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

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Time (LST=GMT+2). Where 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 [44] and other tests proposed by various authors [45-46]. Details about the quality control procedures used in this study are given by Pashiardis and Kalogirou [47]. All data that do not meet the conditions specified by the suggested tests are not used in the study.

Regarding the UV irradiance (UVB+UVA), the following upper limits were applied as suggested by Miguel et al. [48]:

$$UVB \le 1.2 * UVB_0 \quad \text{and} \quad UVA \le 1.2 * UVA_0 \qquad (1)$$

where, UVB and UVA are the measured irradiance values and UVB_0, UVA_0 are the horizontal extraterrestrial solar UVB and UVA irradiances. The solar constants of UVB and UVA have the following values: $UVB_{sc} = 19.02$ and $UVA_{sc} = 70.64$ W m^{-2} [15]. The measurements of both stations were less than the horizontal extraterrestrial solar UVB and UVA irradiation during the whole period of measurements (Figure 1). The values of UVB and UVA irradiances during the night were close to zero. No other errors were detected. However, long periods of missing records were detected during the measurement period at Larnaca due to instability of the system.

Regarding the quality control of the daily UV (A+B) radiation data, daily values were rejected in case of incomplete data during the day. The time series plots of the daily values of UV and global 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 a lot of fluctuations in the spring season, while the descent is smoother. During summer the daily UV radiation exceeds the value of 2000 kJ m^{-2} at Larnaca and 1800 kJ m^{-2} at Athalassa, while during the winter season the lowest daily value is about 110 kJ m^{-2} at both stations. The relationship of UV and global radiation is evident from the graph. 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. 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.

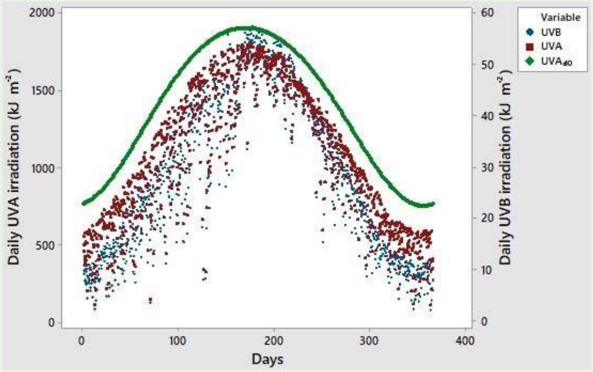

Figure 1: Daily values of UVA and UVB irradiation (kJ m^{-2}) at Athalassa and daily extraterrestrial UVA (UVA$_{d0}$) irradiation (kJ m^{-2}).

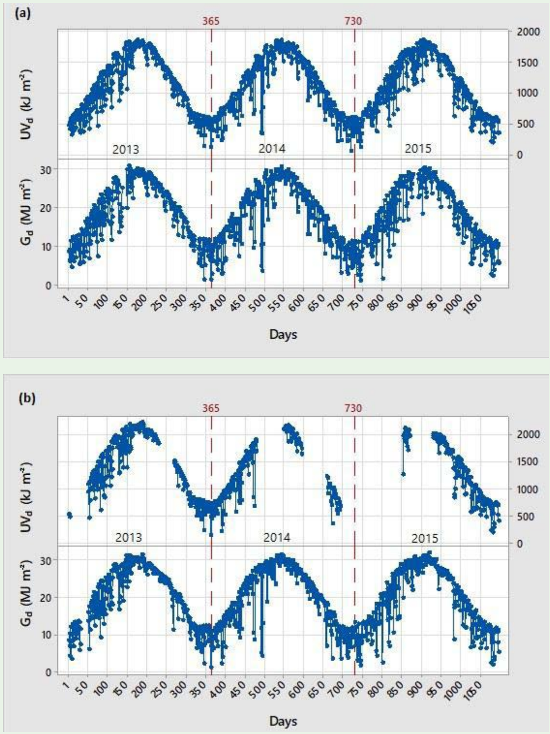

Figure 2: Time series plot of daily UV and global solar irradiation during the period 2013-2015 at a) Athalassa and b) Larnaca.

Results and Discussion

Statistical analysis of hourly UV irradiance

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

Table 1 shows the hourly statistical parameters for July which shows the highest values during the year 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}).Generally, hourly UV irradiances at Larnaca are higher than those at Athalassa.

It can be observed that the median values are close or slightly higher than the average ones, which suggest that the average hourly UV distribution is approaching the normal one.The UV variability is expressed by the coefficient of variation (*CV*). As it can be seen in Table 1, the *CVs* in July are low during the midday (3-9%) at both stations, indicating a high stability along these hours in summer. Furthermore, *CVs* fluctuate between 3 and 16% at Athalassa, while at Larnaca they are slightly higher (3-22%). The standard deviations are lower along midday hours and symmetrically distributed around solar noon during the summer months. This could be explained by a

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Table 1: Statistical estimators of the mean hourly UV 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	CV(%)	Min	Q1	Median	Q3	Max	IQR	P5	P95
6	93	5.12	0.76	14.93	2.35	4.67	5.20	5.62	6.64	0.95	3.64	6.35
7	93	12.42	1.57	12.63	6.70	11.55	12.68	13.42	15.30	1.88	9.32	14.79
8	92	24.42	1.97	8.05	18.51	23.51	24.79	25.62	27.88	2.11	20.62	27.37
9	92	37.00	1.88	5.07	30.94	35.84	37.22	38.28	40.58	2.43	33.71	39.86
10	92	47.97	2.07	4.31	38.16	46.96	48.17	49.20	51.38	2.24	44.79	50.81
11	92	55.91	1.91	3.41	48.80	54.97	56.07	57.37	59.14	2.40	52.59	58.56
12	92	59.62	1.99	3.34	53.35	58.66	59.87	61.01	63.33	2.35	55.26	62.45
13	92	58.74	3.44	5.86	40.12	58.05	59.60	60.71	62.48	2.66	50.16	61.75
14	92	53.06	5.08	9.57	30.93	52.74	54.92	55.87	57.44	3.13	40.83	57.02
15	92	43.84	7.08	16.14	17.21	44.31	46.66	47.49	49.23	3.18	23.98	48.57
16	92	34.33	4.38	12.75	7.00	34.18	35.59	36.51	38.22	2.34	24.48	37.37
17	92	23.01	2.08	9.03	11.37	22.58	23.47	24.14	25.78	1.56	19.16	25.04
18	92	11.60	1.00	8.64	7.18	11.06	11.72	12.29	13.41	1.23	9.94	13.18
19	92	5.56	0.58	10.38	2.96	5.22	5.55	5.90	6.74	0.68	4.73	6.44

b) Larnaca

Hour	N	Mean	StDev	CV(%)	Min	Q1	Median	Q3	Max	IQR	P_5	P_{95}
6	77	5.17	1.13	21.91	2.16	4.44	5.05	6.05	7.56	1.60	3.62	7.15
7	77	13.37	2.77	20.74	9.39	11.12	12.38	15.98	19.35	4.85	9.88	18.23
8	77	27.30	3.84	14.07	19.79	24.42	26.27	30.87	34.84	6.45	20.85	33.51
9	77	41.95	4.12	9.81	30.27	39.04	42.15	45.54	49.35	6.50	34.94	48.35
10	77	55.14	3.80	6.89	42.68	52.28	55.60	58.10	61.82	5.81	49.32	60.97
11	77	64.98	3.27	5.03	53.99	62.51	65.36	67.08	70.75	4.57	59.82	69.99
12	77	70.63	2.83	4.00	63.48	68.64	71.32	72.46	75.63	3.81	65.39	74.98
13	77	70.91	2.65	3.74	61.36	69.45	71.05	72.78	75.40	3.34	65.87	74.41
14	77	66.01	2.50	3.78	61.33	63.90	65.98	68.16	70.42	4.27	61.71	69.83
15	77	56.06	4.21	7.50	46.34	54.58	55.82	58.50	61.75	3.92	52.84	60.41
16	77	42.62	3.96	9.28	24.61	41.05	42.96	44.79	49.06	3.74	32.53	47.44
17	77	28.01	2.97	10.62	16.75	25.30	27.91	30.36	33.33	5.06	24.11	32.80
18	77	13.57	2.03	14.93	5.17	11.79	13.67	15.03	17.06	3.23	11.08	16.63
19	68	7.03	0.88	12.57	4.59	6.46	7.10	7.82	8.50	1.36	5.67	8.25

minor presence of clouds in the summer months that lead to a high stability.

The differences between the maximum and the values of *Q3* quartiles are low, with the highest ones not exceeding 2.32 W m^{-2} for Athalassa and 4.27 W m^{-2} for Larnaca; similarly, the differences between the maximum values and the 95 percentiles are even lower with the highest ones not exceeding 0.88 W m^{-2} for Athalassa and 1.62 W m^{-2} for Larnaca; these results show that the maximum values are representative of the UV irradiance. On the other hand, the differences between *Q1* quartiles and minimum values are relatively high (>5 W m^{-2}) in most cases for both stations. Similarly, the differences between the minimum values (*Min*) and the 5 percentiles, P_5, are higher than 4 W m^{-2} at both stations, which suggests that the minimum values are not representative of the UV irradiance at the station level and correspond to unusual extreme values. Similar results have been obtained by Martinez-Lozano et al. [30], Foyo-Moreno et al. [31] and Bilbao et al. [11] for a number of stations in Spain. The absolute maximum values of the two stations are 63.33 W m^{-2} for Athalassa and 75.63 W m^{-2} for Larnaca.

Monthly average hourly UVT irradiance: The daily variation of the average hourly UVT irradiance is shown in Figure 3. The figure shows that UVT irradiance fluctuates between 22.75W m^{-2} in December and 59.62 W m^{-2} in July at solar noon at Athalassa. The values at Larnaca are higher than in Athalassa and they fluctuate between 29.17 W m^{-2} in December and 70.63 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.

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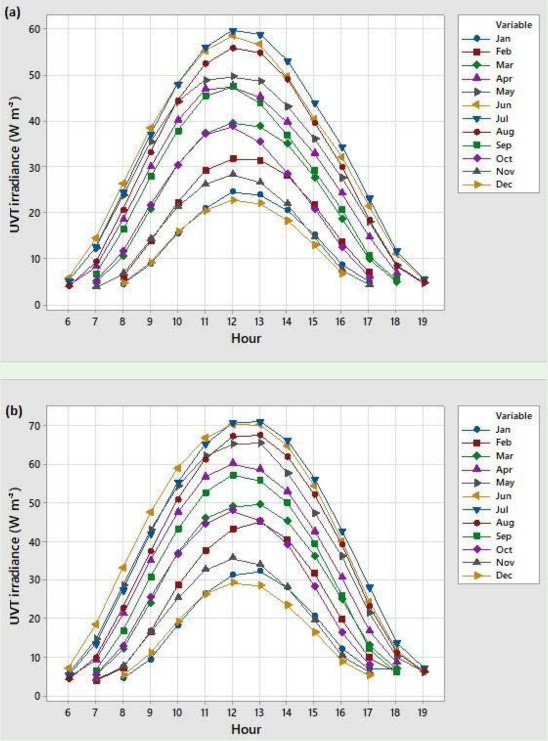

Figure 3: Daily evolution of the monthly mean hourly UVT irradiance (W m^{-2}) for the period 2013-2015 at a) Athalassa and b) Larnaca.

Accumulated hourly UVT irradiation: In the studies on the biological effects of UVT irradiation or the availability of solar energy for technological applications, we require the accumulated UVT solar irradiation (kJ m^{-2}) through a period of time. Table 2 shows the accumulated hourly UVT irradiation values for an average day of each month and the last value is the total daily amount. It can be seen that the highest value for UVT irradiation was produced in July, with a daily average of 1701.4 kJ m^{-2} for Athalassa, while at Larnaca the highest is recorded in June (2060.4 kJ m^{-2}). On the other hand, in December the average energy received was a minimal 476.2 kJ m^{-2} at Athalassa and 622.4 kJ m^{-2} at Larnaca. The ratio between the highest and the lowest values is 3.6 for Athalassa and 3.3 for Larnaca. Similar values were obtained by Ogunjobi and Kim [49] at Kwangju city (South Korea). Canada et al [50] found a ratio of 5 at the Spanish cities of Cordoba and Valencia. Similar ratio was found by Bilbao et al [29] at Valladolid, Spain.

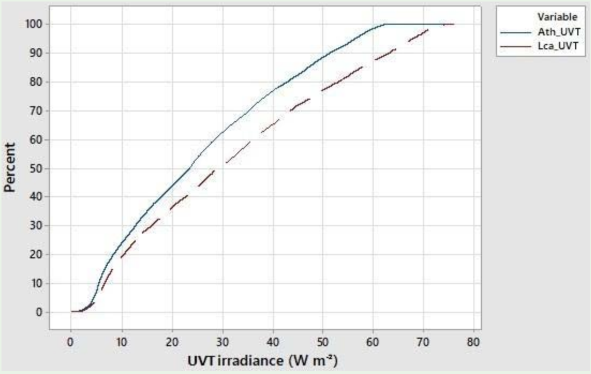

Figure 4: Cumulative Density Functions (CDFs) of the UVT irradiances of both stations.

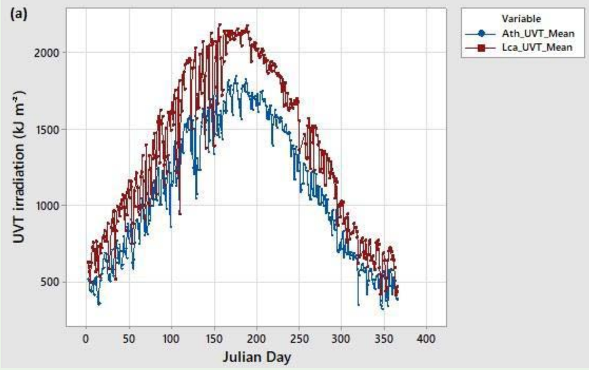

Figure 5a: Average daily UVT irradiation (kJ m^{-2}) for each day of the year at Athalassa and Larnaca, during the period 2013-2015.

Frequency of hourly UVT irradiances: The Cumulative Density Functions (CDFs) of the UVT irradiances of both stations are shown in Figure 4. As the figure indicates that in 60% of hourly values the UVT irradiances at Athalassa are lower than 28.5 W m^{-2} while at Larnaca are lower than 36 W m^{-2}.

Statistical analysis of daily UVT irradiation

Daily and monthly average daily UVT irradiation values have been calculated. Figure 5a shows the average daily values of UVT for each day of the year for both stations. The daily values present

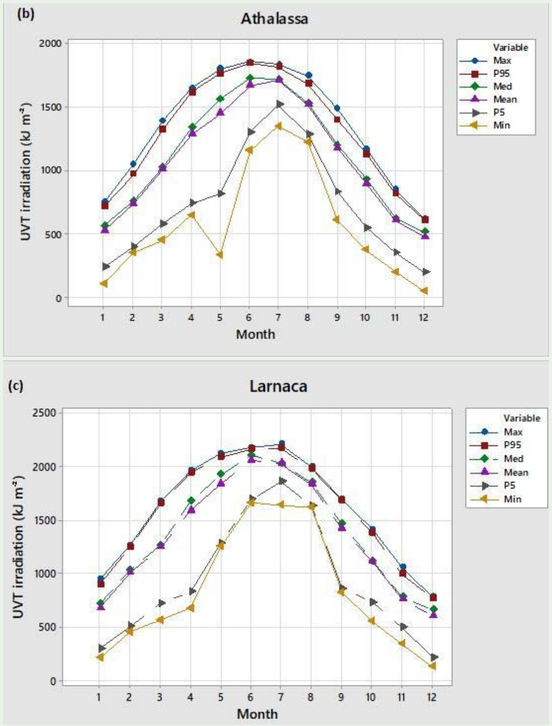

Figure 5b and 5c: Monthly variation of the statistical parameters of UVT daily irradiation at a) Athalassa and b) Larnaca.

Table 2: Accumulated hourly UVT 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
05:00 - 06:00				14.9	18.7	20.7	18.4	14.1				
06:00 - 07:00			16.6	44.4	63.1	72.3	63.2	47.2	23.8	18.3	13.3	
07:00 - 08:00	15.9	21.2	54.6	110.6	148.3	167.0	151.1	121.2	82.3	60.1	37.4	16.7
08:00 - 09:00	47.4	70.3	129.3	218.0	275.7	304.8	284.3	240.4	182.1	138.1	88.4	49.4
09:00 - 10:00	103.0	149.9	238.6	362.2	434.8	477.6	457.0	400.0	318.0	247.4	164.9	106.2
10:00 - 11:00	178.4	254.7	372.7	530.5	610.5	676.4	658.3	588.4	481.2	380.7	258.8	179.4
11:00 - 12:00	266.7	369.0	514.9	701.4	788.8	887.0	872.9	789.4	651.9	520.3	360.4	261.3
12:00 - 13:00	352.8	482.1	654.1	863.8	963.6	1090.5	1084.3	986.3	809.8	647.5	455.7	340.2
13:00 - 14:00	426.3	582.9	779.8	1006.2	1118.6	1268.8	1275.4	1163.0	942.2	750.1	533.8	405.8
14:00 - 15:00	481.1	660.3	879.1	1124.1	1248.2	1413.7	1433.2	1305.0	1046.6	824.9	586.3	451.9
15:00 - 16:00	512.4	709.0	946.4	1210.9	1347.3	1529.3	1556.8	1412.8	1120.5	869.6	612.9	476.2
16:00 - 17:00	529.9	733.7	981.8	1263.5	1411.9	1606.2	1639.7	1478.9	1158.1	890.8	628.0	
17:00 - 18:00			999.4	1288.0	1442.1	1645.5	1681.4	1509.3	1177.7			
18:00 - 19:00					1458.7	1664.5	1701.4	1526.5				

b) Larnaca

Hour	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
05:00 - 06:00				16.3	20.4	25.6	18.6	14.8				
06:00 - 07:00		13.5	18.6	48.9	72.5	91.6	66.8	50.1	22.9	19.2	15.1	
07:00 - 08:00		39.1	61.8	124.6	174.7	210.6	165.0	132.1	83.0	65.6	41.7	18.7
08:00 - 09:00	15.9	98.3	148.2	250.2	328.8	381.0	316.1	266.2	192.9	156.9	100.4	58.1
09:00 - 10:00	49.3	200.5	280.9	420.8	524.0	592.9	514.5	449.0	347.7	288.5	191.0	127.1
10:00 - 11:00	114.6	335.5	445.9	624.4	747.1	832.5	748.5	669.1	536.6	448.3	307.7	221.5
11:00 - 12:00	209.8	490.4	621.8	840.5	981.0	1085.3	1002.7	910.5	742.0	620.7	435.5	326.5
12:00 - 13:00	321.8	652.5	799.7	1050.9	1216.7	1337.8	1258.0	1153.4	942.7	783.3	557.5	428.8
13:00 - 14:00	437.5	798.0	961.9	1240.9	1424.0	1570.5	1495.6	1376.3	1122.2	924.0	658.0	513.0
14:00 - 15:00	538.1	911.0	1091.8	1393.7	1594.2	1765.6	1697.4	1563.1	1264.1	1025.4	728.0	572.0
15:00 - 16:00	612.6	981.2	1181.5	1503.0	1723.8	1909.1	1850.9	1703.6	1356.9	1084.0	764.9	603.7
16:00 - 17:00	656.1	1016.3	1228.3	1562.8	1800.5	1996.4	1951.7	1786.5	1400.1	1112.8	786.9	622.4
17:00 - 18:00	681.1	1038.3	1253.4	1593.5	1836.5	2038.1	2000.6	1826.3	1421.3			
18:00 - 19:00					1858.3	2060.4	2025.9	1848.7				

a greater fluctuation in spring season. The highest daily values are recorded in June and July and the lowest in December.

The annual evolution of the most relevant statistical parameters is shown in Figure 5b and 5c. As it can be seen in Figures 5b and 5c, the differences found between the absolute minimums and the 5 percentiles are greater than the ones found between the absolute maximums and the 95 percentiles for both stations, which indicates that the minimums are not representative of UVT irradiation levels and correspond to unusual extreme values. Furthermore, the median values are close to the average ones throughout the year. Similar results were obtained by Bilbao et al. [29] in Valladolid, Spain.

A more detail information of all calculated statistics of the daily UVT for all-sky conditions is shown in Table 3. The observed daily maximum is occurred in June at Athalassa (1852 kJ m^{-2}) and in July at Larnaca (2210 kJ m^{-2}). The Coefficient of Variation (CV) is less than 10% in the summer months, indicating stability of weather conditions at both stations during this season. According to the classification of the distribution types as a function of skewness and kurtosis coefficients [51], the most frequent distribution of the daily irradiation at Athalassa is Type IV (almost normal with negative tail) and is occurred on 7 occasions. The second frequent type is V (narrow peak with negative tail) and is recorded in 5 months. At Larnaca, the most frequent distribution of the daily irradiation is Type V (7 months), with the second one of Type IV (4 months). November is characterized by Type I which is a normal distribution. Almost similar results were obtained by Kudish and Evseev [51] for the daily UVA irradiation at Beer Sheva, Israel.

The accumulated UVT irradiation received in an average year is 398.4 MJ m^{-2} for Athalassa and 494.4 MJ m^{-2} for Larnaca. These values are much higher than those obtained by other researchers.

Citation: Pashiardis S, Kalogirou SA and Pelengaris A. Statistical Analysis and Inter-Comparison of Solar UV and Global Radiation for Athalassa and Larnaca,Cyprus. SM J Biometrics Biostat. 2017; 2(2): 1012.

Table 3: Statistical estimators of the daily UVT irradiation values (kJ m^{-2}) at a) Athalassa and b) Larnaca, during the period 2013-2015.

a) Athalassa

Month	N	Mean	StDev	CV(%)	Min	Q1	Med	Q3	Max	IQR	As	K	P_5	P_{95}	D.type
1	93	525.4	143.2	27.26	108.6	419.3	561.5	636.1	746.0	216.8	-0.71	-0.19	238.1	714.6	IV
2	84	733.7	159.6	21.75	355.6	665.7	756.6	839.2	1046.0	173.5	-0.60	-0.05	398.7	966.9	IV
3	92	1005.8	221.2	22.00	448.2	880.4	1021.8	1189.2	1387.0	308.8	-0.55	-0.24	576.9	1317.2	IV
4	90	1281.6	252.1	19.67	643.8	1127.8	1335.6	1452.2	1643.8	324.4	-0.75	-0.06	736.4	1612.9	IV
5	90	1446.6	300.2	20.75	329.7	1297.5	1560.9	1644.6	1794.3	347.1	-1.64	3.03	815.5	1761.4	V
6	90	1660.0	172.8	10.41	1154.1	1560.3	1723.8	1796.6	1852.5	236.4	-1.12	0.45	1299.9	1839.0	IV
7	92	1701.5	92.1	5.41	1343.9	1657.4	1716.3	1764.2	1830.9	106.8	-1.34	2.22	1512.0	1811.6	V
8	93	1511.7	105.4	6.97	1219.3	1453.8	1523.5	1578.5	1744.9	124.7	-0.50	0.26	1285.4	1678.4	IV
9	90	1171.8	168.1	14.34	605.2	1088.6	1195.1	1297.3	1482.1	208.8	-0.89	0.82	832.3	1393.5	V
10	93	890.8	173.1	19.43	372.0	781.6	929.1	1015.7	1165.7	234.2	-0.81	0.38	548.6	1130.0	IV
11	90	603.4	121.0	20.06	198.1	548.6	621.7	661.4	850.2	112.8	-0.75	1.67	352.3	817.5	V
12	92	471.6	133.0	28.20	43.3	409.4	515.6	578.2	615.9	168.8	-1.24	0.92	195.0	605.9	V
All	1089	1084.6	461.2	42.52	43.3	651.0	1075.3	1522.3	1852.5	871.3	-0.01	-1.28	403.1	1766.5	VI

b) Larnaca

Month	N	Mean	StDev	CV(%)	Min	Q1	Med	Q3	Max	IQR	As	K	P_5	P_{95}	D.type
1	33	679.6	156.9	23.09	212.7	576.8	721.2	782.9	950.2	206.0	-1.03	1.42	299.5	897.7	V
2	38	1008.8	170.3	16.88	457.1	951.5	1035.8	1136.1	1267.8	184.7	-1.48	3.29	507.5	1247.5	V
3	62	1244.9	282.2	22.67	568.6	1023.3	1267.7	1492.9	1673.2	469.6	-0.44	-0.59	725.6	1654.7	IV
4	54	1585.6	306.5	19.33	676.5	1451.2	1674.7	1821.9	1958.2	370.7	-1.18	1.01	829.5	1941.0	V
5	49	1837.0	232.1	12.63	1251.0	1711.7	1923.7	2018.6	2120.9	306.9	-1.10	0.49	1285.1	2090.3	IV
6	30	2055.2	129.5	6.30	1662.2	2056.1	2103.7	2134.5	2176.3	78.4	-2.08	3.67	1693.2	2162.7	V
7	77	2022.9	99.3	4.91	1637.8	1967.1	2027.8	2087.1	2210.1	119.9	-0.73	1.78	1857.8	2170.1	V
8	66	1832.7	106.4	5.81	1620.7	1783.7	1848.8	1918.8	1994.8	135.1	-0.51	-0.70	1633.8	1980.6	IV
9	35	1416.5	205.3	14.49	824.0	1356.5	1463.3	1518.6	1693.7	162.0	-1.34	2.10	862.6	1685.4	V
10	74	1110.7	192.3	17.31	553.6	1007.9	1120.8	1264.0	1411.1	256.1	-0.69	0.39	732.5	1379.2	IV
11	82	762.4	142.7	18.72	340.5	676.9	785.7	837.6	1059.1	160.6	-0.27	0.17	496.7	997.1	I
12	62	605.0	160.5	26.53	128.6	522.7	663.9	727.3	784.2	204.6	-1.29	1.08	219.1	770.6	V
All	662	1335.0	536.6	40.19	128.6	829.4	1314.8	1861.7	2210.1	1032.3	-0.04	-1.33	552.0	2097.9	VI

Martinez-Lozano et al. [30] found a value of 191 MJ m^{-2} in Valencia, Spain; Bilbao et al. [29] found a value of 245 MJ m^{-2} in Valladolid, Spain, while Ogunjobi and Kim [49] reported a value of 251 MJ m^{-2} in Kwangju, South Korea. However, Kudish and Evseev [51] found a value of 352 MJ m^{-2} for the accumulated UVA irradiation received in an average year, at Beer Sheva, Israel, which is very close to the value estimated in Cyprus, if we also take into consideration the UVB irradiation.

It is also interesting to estimate the average daily UVT for different levels of global solar irradiation (Table 4). Most automatic stations are equipped with global radiation sensors. Therefore, it is possible to estimate daily UVT based on solar global radiation measurements. The most frequent cases are recorded in the ranges of daily global irradiation of 10-14 and 24-30 MJ m^{-2}.

In order to compare the various components of UV radiation, Table 5 shows the monthly average daily values of UVER, UVB, UVA, UVT and global solar irradiation at both stations. Larnaca shows the highest values of all UV components throughout the year, except the ultraviolet erythema radiation (UVER). Generally, the monthly mean daily UVT values are higher than those in Valladolid, Spain [29].

Monthly mean daily UV ratios: The daily UV irradiation during clear days is the highest expected on the Earth's surface and is defined as the potential UV irradiation (UV_p). The monthly mean daily values of the UV potential (UV_p), the extraterrestrial (UV_0) and the measured (UV) irradiation were calculated and the ratios between these variables were estimated. The ratio UV/UV_0 (UV clearness index or hemispherical transmittance) represents information about the percentage of radiation 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 UV potential to UV extraterrestrial, (UV_p/UV_0), gives information about the atmospheric transparency on clear days, i.e, without clouds but with aerosols, though in low proportion. The ratio of UV/UV_p, represents the observed UV irradiation fraction

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Table 4: Daily UVT irradiation (kJ m^{-2}) statistics at different ranges of daily global solar radiation (MJ m^{-2}).

		Athalassa						Larnaca					
Global (MJ/m2)		Occur.	UVT_d (kJ m^{-2})					Occur.	UVT_d (kJ m^{-2})				
Lower	Upper		Mean	Median	Min	Max	Std. Dev.		Mean	Median	Min	Max	Std. Dev.
0	2	4	122.6	118.5	108.6	149.5	18.36	2	158.0	187.4	128.6	187.4	41.56
2	4	14	232.3	215.6	183.6	329.7	41.01	6	267.9	270.5	212.7	340.5	58.46
4	6	25	340.7	346.4	281.9	422.1	33.42	4	402.3	417.9	351.0	431.5	35.44
6	8	41	423.1	423.7	342.6	478.5	33.07	25	522.6	510.2	457.1	636.8	48.58
8	10	59	517.7	512.2	450.7	643.8	39.51	28	618.8	608.5	555.1	718.7	43.29
10	12	119	612.9	596.7	518.9	776.9	54.35	63	725.6	721.2	614.8	893.1	50.72
12	14	90	702.3	700.2	583.7	925.8	61.59	68	830.6	818.8	568.6	1022.1	78.23
14	16	72	839.3	842.4	605.2	1001.8	69.66	43	991.7	992.8	874.0	1091.3	52.85
16	18	81	970.3	968.4	776.3	1165.3	69.84	50	1102.7	1098.1	824.0	1306.1	91.58
18	20	64	1080.1	1086.2	882.3	1221.1	71.71	42	1243.6	1251.0	872.2	1411.1	94.45
20	22	76	1224.8	1238.1	1021.6	1390.8	73.72	43	1398.9	1403.1	1187.9	1530.8	84.56
22	24	79	1354.8	1348.9	1212.3	1533.8	79.20	29	1534.7	1527.1	1385.7	1671.8	76.68
24	26	91	1486.8	1500.1	1307.5	1629.3	71.51	53	1683.3	1673.2	1567.3	1852.2	68.43
26	28	110	1623.1	1630.5	1466.2	1744.9	60.87	76	1860.7	1861.2	1650.3	2016.9	71.87
28	30	106	1739.0	1748.9	1542.7	1839.2	55.65	84	2008.3	2009.9	1873.9	2119.4	64.16
30	32	18	1823.5	1830.0	1773.4	1852.5	20.11	44	2105.5	2120.9	1970.4	2210.1	60.21

Table 5: Monthly average daily values of UVER, UVB, UVA, UVT and global solar irradiation at both stations.

	Athalassa					**Larnaca**				
Month	**$UVER_d$**	**UVB_d**	**UVA_d**	**$UV(A+B)_d$**	**G_d**	**$UVER_d$**	**UVB_d**	**UVA_d**	**$UV(A+B)_d$**	**G_d**
	kJ m^{-2}	kJ m^{-2}	kJ m^{-2}	kJ m^{-2}	MJ m^{-2}	kJ m^{-2}	kJ m^{-2}	kJ m^{-2}	kJ m^{-2}	MJ m^{-2}
1	1.2	9.9	515	525	9.4	1.0	14.7	676	691	10.0
2	1.8	15.6	718	734	13.3	1.5	23.0	984	1009	14.3
3	2.6	23.4	973	997	17.5	2.1	32.1	1213	1245	18.6
4	3.5	31.8	1250	1282	22.3	2.9	43.6	1551	1586	23.9
5	4.3	38.9	1408	1447	24.1	3.5	52.4	1791	1837	26.4
6	5.3	48.0	1613	1661	27.8	4.2	60.7	1996	2055	29.5
7	5.5	50.6	1651	1701	28.0	4.2	60.4	1963	2023	29.3
8	4.8	43.8	1468	1512	24.9	3.7	52.2	1798	1833	26.3
9	3.5	31.7	1140	1172	20.1	2.9	42.5	1400	1416	21.7
10	2.4	21.1	870	891	15.5	1.9	28.7	1083	1111	16.7
11	1.5	12.3	596	608	11.4	1.1	16.9	745	762	11.4
12	1.0	8.7	468	476	8.8	0.8	12.9	592	605	9.4
All	3.1	28.0	1057	1085	18.5	2.6	37.1	1306	1337	19.9

which corresponds to cloud-free sky, i.e., this attenuation is due to cloudiness and aerosols.

Figure 6a shows the monthly average daily values of extraterrestrial (UV_0), the potential (UV_p) and measured UV irradiation at Athalassa. The graph shows that the maximum of UV_0 and UV_p variables is recorded in June, but the maximum of the measured UV is recorded in July. The difference between UV_p and UV 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 [42-43].

Figure 6b shows the monthly means of the above ratios for Athalassa. The greatest variability is shown in the ratio of UV/UV_0. The evolution of these ratios increases from spring to summer and decreases from summer to winter. The maximum of UV/UV_0 *is 0.7,* while the ratio UV/UV_p is close to one in the summer.

Frequency distribution of daily UV irradiation: The cumulative frequency function of the daily UVT irradiation of both stations is shown in Figure 7. The figure indicates that in 60% of the year, the daily sums of UVT irradiation at Athalassa are below 1270 kJ m^{-2}, while at Larnaca for the same value of probability is about 1567 kJ m^{-2}.

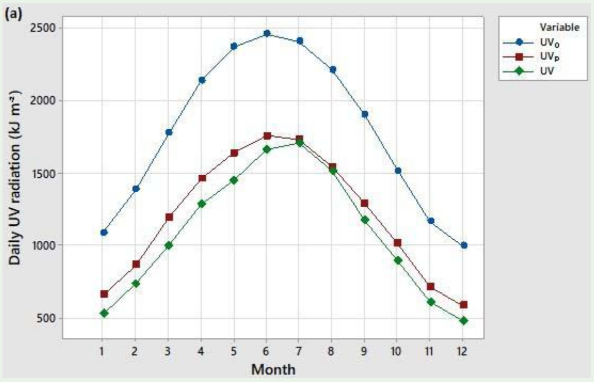

Figure 6a: Annual variation of monthly mean values of daily extraterrestrial (UV_0), potential (UV_P) and measured UV irradiation at Athalassa.

Relationships between UVT and other variables

Relationship between ultraviolet solar radiation and global solar radiation: Given the time evolution of UVT and global solar radiation (Figure 2), a linear correlation between them is performed. The linear regression has the following form: $UVT = a*G$. There is no intercept since it is assumed that both radiations reach zero at the same time. The analysis on a monthly basis was performed only for Athalassa, since there are a lot of missing data at Larnaca. Table 6 shows the results of the fit parameters of the above equation for the hourly (W m^{-2}) and daily values (kJ m^{-2}) at Athalassa. The characteristic of these relationships is that the coefficients of determination (R^2) are close to 1. It can be seen that the maximum values of UV radiation with respect the global solar radiation occur in the summer months and the minimum in winter for both the hourly and daily values. Therefore, the solar zenith angle appears to be the major factor of the ratio UV/G (slope 'a'). Ozone and aerosols have a smaller influence than the annual zenith angle cycle. For the whole period of measurements the following relationships have been obtained for both stations:

Athalassa: $UV_h = 0.059*G_h$ and $UV_d = 0.059*G_d$ (2)

Larnaca: $UV_h = 0.068*G_h$ and $UV_d = 0.068*G_d$ (3)

The subscripts 'h' and 'd' represents the hourly and daily data, respectively. The above relationships indicate that UVT irradiation corresponds to 5.9% and 6.8% of the horizontal global solar irradiation. These values are much higher than those obtained in other regions. Bilbao et al. [29] reported a value of 4.2% in Valladolid, Spain. Martinez-Lozanoet al. [52] found slightly lower values (3.3%) in Valencia, Spain. Similarly, Jacovides et al. [17] reported values around 3.3% for Athalassa for the year 2004, while Koronakis et al. [33] found a value of 4.1% for Athens.

Assuming relations of the form: $UVT = a*G^b$ we obtain the following expressions:

Athalassa: $UV_h = 0.029*G_h^{1.107}$ and $UV_d = 0.046*G_d^{1.076}$ (4)

Larnaca: $UV_h = 0.035*G_h^{1.1004}$ and $UV_d = 0.068*G_d$ (5)

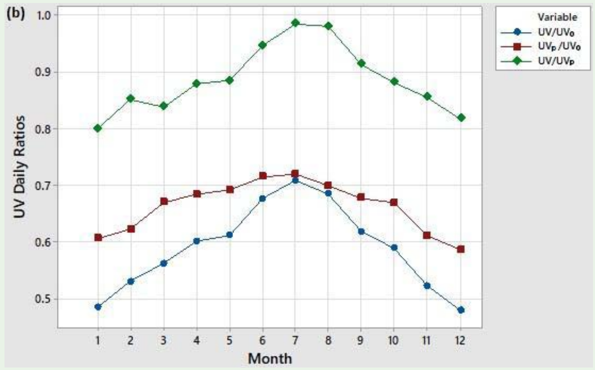

Figure 6b: Monthly mean daily values of the ratios UV/UV_P, UV_P/UV_0, and UV/UV_0 at Athalassa.

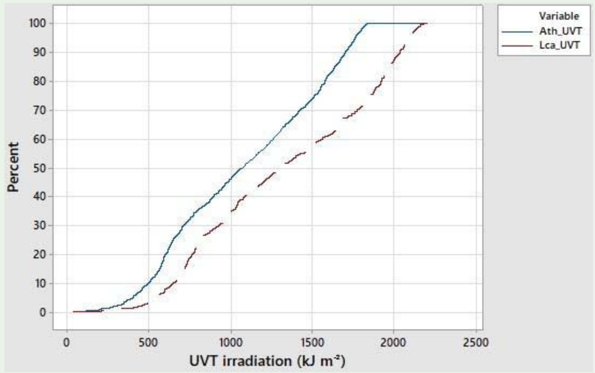

Figure 7: Annual cumulative frequency distribution of daily UVT irradiation at both stations.

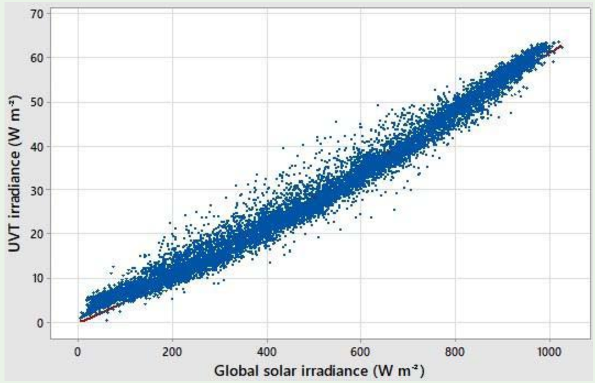

Figure 8: Relationship between UVT irradiance and global solar irradiance for the hourly data during the measurement period at Athalassa. The fitted line has the following form: $UV_h = 0.029*G_h^{1.107}$.

The relationship of the hourly data, obtained from the above expression for Athalassa is shown in Figure 8. The monthly values of 'a' range between 0.026 and 0.098, with the lowest values occurring in the summer and the highest values occurring in winter. The coefficient 'b' ranges between 0.896 and 1.129 with the highest values in the summer period. Bilbao et al. [29] obtained a value of a=0.068 and b=0.9313 for the hourly data and a=0.073 and b=0.9410 for

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Table 6: Parameters of linear relationship UVT=a*G for hourly and daily values at Athalassa.

Month	Hourly		Daily	
	a	R^2	a	R^2
1	0.053	0.990	0.055	0.932
2	0.055	0.993	0.055	0.945
3	0.056	0.994	0.056	0.964
4	0.058	0.993	0.057	0.937
5	0.060	0.995	0.059	0.973
6	0.061	0.995	0.060	0.906
7	0.061	0.997	0.061	0.916
8	0.061	0.997	0.061	0.900
9	0.059	0.993	0.058	0.840
10	0.057	0.994	0.057	0.937
11	0.053	0.994	0.054	0.930
12	0.052	0.990	0.053	0.982
All	0.059	0.993	0.059	0.993

daily data in Valladolid, Spain. Cañada et al. [53] obtained a value of a=0.047 and b=0.92 for hourly data in Valencia, Spain. Therefore, each location has its own coefficients.

Influence of solar elevation and cloudiness on UVT irradiation: The most important factor which affects the solar radiation is the solar elevation. This variable determines the optical path of solar rays from the top of the atmosphere until they reach the Earth's surface. The solar elevation is related to the optical air mass, that is defined as the ratio between the relative optical air mass in a given direction and the optical mass in a vertical direction and is calculated using the equation suggested by Kasten and Young [19]:

$$m = 1/(\cos\theta_z + 0.050572(96.07995 - \theta_z)^{-1.6364}) \quad (6)$$

where θ_z is the zenith angle of the Sun (complementary angle of the solar elevation).

To quantify the effect of solar elevation on UVT irradiance, the optical air mass, m, was calculated at the midpoint of each hour. Figure 9 shows relationship between UVT irradiance and the optical air mass (m) for three different classes of hourly clearness index (k_t) i.e., (k_t)>0.65 (clear hours), 0.35<k_t<0.65 (partly cloudy hours) and k_t<0.35 (cloudy hours). Similar graph was obtained from Larnaca. It can be seen that, despite the wide dispersion of data, the values of UVT irradiance decrease with increasing optical air mass. The highest values of UVT irradiance are obtained at low optical air mass. The range of dispersion of the data for the case of clear hours is smaller comparing to the other two classes. The relationships between UVT and optical air mass have the following form: $UVT = a * m^b$. Table 7 shows the results of the above analysis for both stations.

UVT irradiance and the optical air mass (m) for three different classes of hourly clearness index (k_t) i.e., (k_t)>0.65 (clear hours), 0.35<k_t<0.65 (partly cloudy hours) and k_t<0.35 (cloudy hours). Similar graph was obtained from Larnaca.

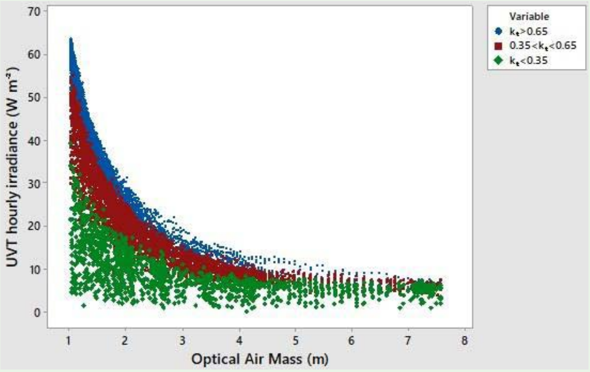

Figure 9: Dependence of hourly UVT irradiance (W m^{-2}) on optical air mass (m) for three different classes of clearness index (k_t) at Athalassa.

Empirical models for any atmospheric condition: Some authors have proposed different empirical models for hourly UV irradiance based on the clearness index (k_t), the UV clearness index (k_{tUV}), and optical air mass (m). The hourly clearness index is defined as:

$$k_t = G / G_0 \quad (7)$$

where G is the hourly measured global solar irradiance on a horizontal surface and G_0 is the hourly extraterrestrial solar irradiance. By analogy the UV clearness index is defined as the ratio of the measured UV irradiance on horizontal surface to the hourly UV extraterrestrial irradiance

$$k_{tUV} = UV / UV_0 \quad (8)$$

The hourly extraterrestrial UV radiation (UV_0) is calculated by the following formula:

$$UV_0 = (12/\pi) * UV_{SC} * \varepsilon * [\sin\phi \sin\delta * (\pi(\omega_2 - \omega_1)/180) + \cos\phi \cos\delta (\sin\omega_2 - \sin\omega_1)] \quad (9)$$

Where ε is the eccentricity, φ is the latitude, δ is the solar declination, ω_1 and ω_2 *are* the hour angles at the starting and ending time of one hour time interval and $UV_{SC} = 80.83$ W m^{-2}, which was obtained from Gueymard [54]. The respective solar constant for the global solar radiation is $G_{SC} = 1366.1$ W m^{-2}.

Four empirical models were selected for the estimation of the hourly UV solar irradiance. The first model was proposed by Foyo-Moreno et al. [55] and it is based on the relationship between k_{tUV} and global clearness index

(k_t) using data from Granada (Spain):

Table 7: Relationship between UVT irradiance (W m^{-2}) and optical air mass (m) for three different classes of clearness index (k_t) at Athalassa and Larnaca.

Hourly Clearness Index (k_t)	Equation
k_t> 0.65	$UVT\_Ath = 60.165 * m^{-1.248}$
0.35 <k_t< 0.65	$UVT\_Ath = 45.492 * m^{-1.184}$
k_t< 0.35	$UVT\_Ath = 19.361 * m^{-0.866}$
k_t> 0.65	$UVT\_Lca = 71.535 * m^{-1.227}$
0.35 <k_t< 0.65	$UVT\_Lca = 52.224 * m^{-1.148}$
k_t< 0.35	$UVT\_Lca = 25.615 * m^{-0.997}$

Citation: Pashiardis S, Kalogirou SA and Pelengaris A. Statistical Analysis and Inter-Comparison of Solar UV and Global Radiation for Athalassa and Larnaca,Cyprus. SM J Biometrics Biostat. 2017; 2(2): 1012.

$$k_{tUV} = \exp(a + b\ln(k_t)) \tag{10}$$

The coefficients a and b is functions of the optical air mass (m):

$$a = -0.851 + 0.433\exp(-(m-0.97)/1.85) + 0.118\exp(-(m-0.97)/1.86) \tag{11}$$

$$b = 0.610 + 0.271\exp(-(m-1.05)/1.62) \tag{12}$$

The second model was proposed by Murillo et al. [56] who suggested the same type of model, with different equations for the coefficients a and b. For the estimations of the two coefficients they used data from Córdoba (Spain):

$$a = -0.324 - 0.15\ln(m) \quad \text{and} \quad b = 0.794 - 0.03\ln(m) \tag{13}$$

The third model was proposed by Barbero et al. [57] and it is based on both the global clearness index and the optical air mass:

$$UV = 0.712 * UV_0 * k_t^{0.771} * m^{-0.254} \tag{14}$$

The fourth model was proposed by Mateos et al. [28] and it is similar to the previous one, but with different coefficients obtained from data from Valladolid (Spain):

$$UV = 0.685 * UV_0 * k_t^{0.749} * m^{-0.193} \tag{15}$$

The four models were tested with the data from Athalassa. The assessment of the models was based on the mean bias error (mbe), the mean-absolute error (mabe) and the root-mean-square error (rmse), which are defined as follows:

$$mbe(\%) = (100/\bar{X}_{mes})*(\sum_{1}^{n}(X_{est} - X_{mes})/n \tag{16}$$

$$mabe(\%) = (100/\bar{X}_{mes})*(\sum_{1}^{n}|X_{est} - X_{mes}|/n \tag{17}$$

$$rmse(\%) = (100/\bar{X}_{mes})*\sqrt{\sum_{1}^{n}(X_{est} - X_{mes})^2/n} \tag{18}$$

where X_{est} is the predicted values, X_{mes} is the measured values, $\bar{X}_{mes}$ is the mean value of the measured data and n is the total data number.

The results of the testing of the above models with data from Athalassa are shown in Table 8. All the models underestimate the UV irradiance. The lowest values of the statistical estimators are obtained from Murillo's model. The second best model is the Barbero model.

By recalibration the Murillo's and Barbero models using data from both stations in Cyprus, the following equations were obtained:

a) Murillo's model

Athalassa: $UV = UV_0\exp(-0.202 - 0.460\ln(m) + (0.874 - 0.398\ln(m))\ln(k_t))$ (19)

Larnaca: $UV = UV_0\exp(-0.054 - 0.361\ln(m) + (0.883 - 0.305\ln(m))\ln(k_t))$ (20)

b) Barbaro's model

Athalassa: $UV = 0.771 * UV_0 * k_t^{0.715} * m^{-0.301}$ (21)

Larnaca: $UV = 0.906 * UV_0 * k_t^{0.743} * m^{-0.252}$ (22)

The coefficients of the above equations for both stations in Cyprus are almost similar to those obtained in Valladolid (Spain) [28].

Table 8: Comparison of statistical estimators of four original UV models at Athalassa.

Model	Equations	mbe(%)	mabe(%)	rmse(%)
Foyo-Moreno	7,8,10,11,12	-10.61	11.57	14.12
Murillo	7,8,10,13	-4.22	8.97	11.25
Barbero	14	-9.63	10.91	13.36
Bilbao	15	-10.08	11.81	14.85

Relationships of the UVT variables between the two stations: The linear relationships of the UVT variables between the two stations for the hourly and daily data are shown below. The coefficient of determination is high for both relations:

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

$$UV_h\_Ath = 0.941 + 0.783UV_h\_Lca \quad R^2 = 0.91 \tag{23}$$

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

$$UV_d\_Ath = -30.64 + 0.835UV_d\_Lca \quad R^2 = 0.95 \tag{24}$$

Global clearness index and ultraviolet clearness index

The definitions of the global clearness index or global hemispherical transmittance (k_t) and the ultraviolet clearness index or ultraviolet hemispherical transmittance (k_{tUV}) are given in section 3.3.3 (Eqs. (7) and (8), respectively). Figure 10a shows the histogram of the hourly global clearness index at Athalassa. Most of the data are concentrated in the range of 0.65-0.75 indicating that clear atmospheric conditions are the prevailing ones in both stations. The influence of clouds on the levels of solar radiation reaching the ground surface was demonstrated by the classification of clearness index into three different classes (see section 3.3.2).

Figure 10b shows the histogram of the hourly values of k_{tUV} at Athalassa.Values above 0.65 have not been obtained. Similar results were obtained by Ogunjobi and Kim [49] and Bilbao et al [29]. This fact indicates that UV radiation experiences high absorption and scattering along its atmospheric path. The Rayleigh scattering is inversely proportional to the fourth power of wavelength (λ^{-4}), therefore, the attenuation for the UV range is higher than for other spectral intervals. Figure 11 shows the histograms of the two indices for Larnaca. The similarities of the graphs of the two stations are evident.

Relationships between hemispherical transmittances: In this section the relationships between the clearness index (global hemispherical

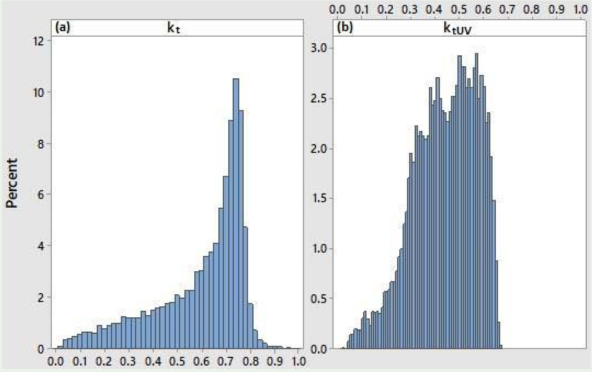

Figure 10: Histograms of global (a) and UV (b) hemispherical transmittances at Athalassa.

Citation: Pashiardis S, Kalogirou SA and Pelengaris A. Statistical Analysis and Inter-Comparison of Solar UV and Global Radiation for Athalassa and Larnaca,Cyprus. SM J Biometrics Biostat. 2017; 2(2): 1012.

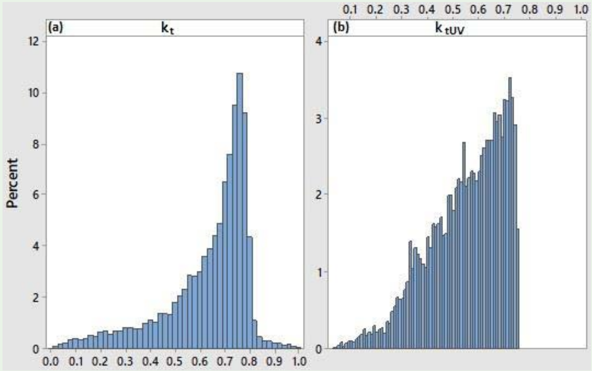

Figure 11: Histograms of global (a) and UV (b) hemispherical transmittances at Larnaca.

transmittance) (k_t) and the UV hemispherical transmittance (k_{tUV}) will be examined. The above results suggest that relationships can be established between the two indices. Three different models were implemented. The small 'k' refers to hourly values, while the capital letter 'K' denotes daily values. Firstly, a linear fit was applied, without intercept of the form: $k_{tUV} = ak_t$. Secondly, a model of the form: $k_{tUV} = ak_t^b$ was tested. The third model is a quadratic equation. The analysis was performed only for Athalassa, since a lot of missing records are observed at Larnaca (Figure 12).

Table 9 shows the results of the linear fit, without intercept, for the hourly and daily data for each month for Athalassa. The annual UV hemispherical transmittance is about 71% of the global hemispherical transmittance. Almost similar values were obtained in Spain [50,55]. The highest values occur in the summer months. The coefficient of determination is close to 1 for both the hourly and daily data.

The second model gave the following equations for the whole data:

Hourly: $k_{tUV} = 0.647 * k_t^{0.665}$ (25) Daily: $K_{TUV} = 0.666 * K_T^{0.847}$ (26)

Table 9: Parameters of linear relationship $k_{tUV} = ak_t$ for hourly and daily values.

Month	Hourly		Daily	
	a	R^2	a	R^2
1	0.709	0.98	0.685	0.99
2	0.717	0.99	0.697	0.99
3	0.730	0.98	0.691	0.99
4	0.734	0.97	0.711	0.99
5	0.766	0.98	0.742	0.99
6	0.771	0.97	0.741	0.99
7	0.789	0.99	0.738	0.99
8	0.786	0.98	0.735	0.99
9	0.737	0.96	0.729	0.99
10	0.700	0.95	0.698	0.99
11	0.673	0.95	0.684	0.99
12	0.683	0.97	0.678	0.99
All	0.742	0.97	0.713	0.99

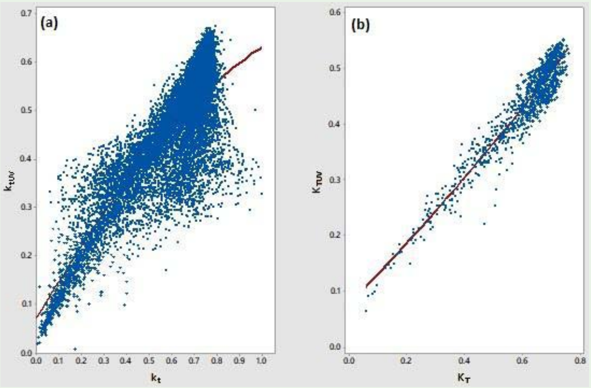

Figure 12: Relationship between hourly (a) and (b) daily UV and global hemispherical transmittances at Athalassa.

Finally, the quadratic model gave the following relationships for the hourly and daily values of Athalassa:

Hourly: $k_{tUV} = 0.067 + 0.804 * k_t - 0.241 * k_t^2 \quad R^2 = 0.68$ (27)

Daily: $K_{TUV} = 0.078 + 0.523 * K_T + 0.103 * K_T^2 \quad R^2 = 0.91$ (28)

Hourly UV/G ratio analysis: The dependence of the UV/G ratio values to the solar elevation angle is shown in Figure 13a. The ratio is increased with solar elevation. Figure 13b shows the dependence of UV/G ratio with global hemispherical transmittance. For high values of k_t (low cloud cover), a light increases in the value of the UV/G ratio can be seen. However, when k_t decreases, an increase in UV/G ratio values can be also observed. It can be concluded that the UV hemispherical transmittance is less affected by clouds than the global hemispherical transmittance. Therefore, the presence of clouds reduces less the component UV than the global solar radiation, due to the strong absorption of water in the near infrared spectrum. Similar results were obtained by other authors: Jacovides et al. [17]; Foyo-Moreno et al. [55] and Bilbao et al. [29]. This fact can be explained by the diffuse component of UV radiation which increases when cloudiness increases [36].

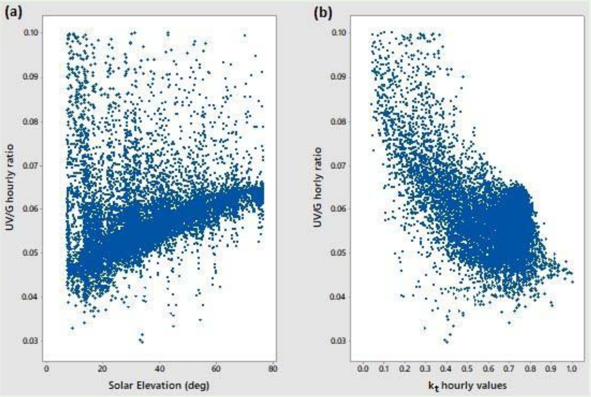

Figure 13 a: Dependence of the hourly UV/G ratio on the solar elevation angle. **b:** Dependence of the hourly UV/G ratio on global hemispherical transmittance (k_t) at Athalassa.

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Table 10: Monthly average daily solar UVB, UVA and UV at Athalassa and Larnaca and their relative differences.

	Ath(UVBd)		Lca(UVBd)			Ath(UVAd)		Lca(UVAd)			Ath(UVd)		Lca(Uvd)		
Month	N	Mean	N	Mean	% Relative	N	Mean	N	Mean	% Relative	N	Mean	N	Mean	% Relative
		kJ/m2		kJ/m2	attenuation		kJ/m2		kJ/m2	attenuation		kJ/m2		kJ/m2	attenuation
1	93	10.0	62	14.7	47.56	93	515.4	31	676.1	31.18	93	525.4	31	691.1	31.54
2	84	15.6	66	23.0	46.85	84	718.1	38	984.1	37.04	84	733.7	38	1008.8	37.49
3	93	23.4	93	32.1	37.27	93	973.2	62	1212.5	24.59	93	996.6	62	1244.9	24.91
4	90	31.8	90	43.6	37.03	90	1249.7	54	1551.0	24.11	90	1281.6	54	1585.6	23.72
5	90	38.9	90	52.4	34.76	90	1407.6	49	1790.9	27.23	90	1446.6	49	1837.0	26.99
6	89	48.0	89	60.7	26.59	89	1612.6	30	1995.8	23.76	89	1660.6	30	2055.2	23.76
7	92	50.6	93	60.4	19.33	92	1650.9	77	1962.8	18.89	92	1701.5	77	2022.9	18.89
8	93	43.8	69	52.2	19.32	93	1467.9	66	1798.1	22.49	93	1511.7	66	1832.7	21.23
9	90	31.7	69	42.5	34.09	90	1140.2	35	1400.3	22.81	90	1171.8	35	1416.5	20.88
10	93	21.1	93	28.7	36.02	93	869.7	74	1082.8	24.50	93	890.8	74	1110.7	24.69
11	89	12.3	90	16.9	37.52	89	595.7	82	745.2	25.10	89	608.0	82	762.4	25.39
12	91	8.7	93	12.9	47.95	91	467.6	62	592.3	26.67	91	476.3	62	605.0	27.02
Year	1087	28.0	997	37.1	32.37	1087	1056.9	660	1305.6	23.53	1087	1083.7	660	1347.7	24.36

Inter-comparison of the two stations

The inter-comparison of the broad-band solar radiation intensity measurements at both sites are reported in Table 10 for the UV radiation components (UVB, UVA and UV). 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:

$$\mathrm{Re}\,lativeAttenuation(\%) = ((X_{Lca} - X_{Ath})/X_{Ath})*100 \qquad (29)$$

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

As indicated in Table 10, the magnitudes of the monthly average daily values of the three types of solar UV 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 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 percentage of relative attenuation of UV ranges between 19 and 37%. The percent of relative attenuation for the solar global and UV radiation between the two sites is presented graphically in Figure 14. As it is indicated from the graph, the differences with respect to the global solar radiation between the two stations are less than 10%.The higher differences in the case of UV radiation are observed in the winter months.

The summary of the inter-comparison of the two sites with respect to UV radiation is presented in Table 11.

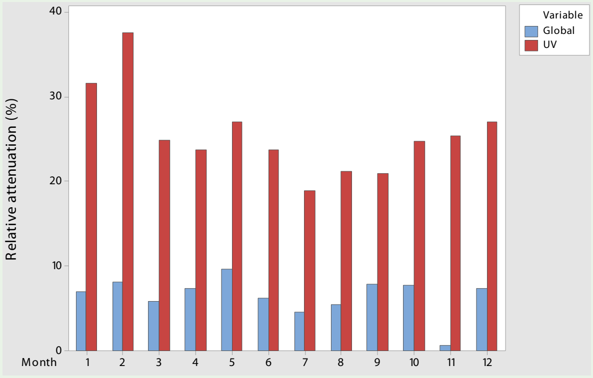

Figure 14: Relative attenuation of solar global and UV radiation for Athalassa and Larnaca.

Table 11: Inter-comparison of the two sites with respect to global and UV radiation.

Variable	Athalassa	Larnaca
Location	inland	coastal
Annual daily average global irradiation (G_d) (MJ m^{-2})	18.53	19.93
Annual total global irradiation (MJ m^{-2})	6835	7183
Annual daily average UVE irradiation (UVE_d) (kJ m^{-2})	3.1	2.6
Annual daily average UVB irradiation (UVB_d) (kJ m^{-2})	28	37
Annual daily average UVA irradiation (UVA_d) (kJ m^{-2})	1056	1316
Annual daily average UV irradiation (UV_d) (kJ m^{-2})	1085	1337
Annual total UV irradiation (MJ m^{-2})	398.4	494.4
Accumulated daily UV irradiation in July (kJ m^{-2})	1701.4	2060.4
Accumulated daily UV irradiation in December (kJ m^{-2})	476.2	622.4
Maximum Hourly Average UV irradiance in July (W m^{-2})	63.3	75.6
Mean annual ratio of hourly UV/G	0.059	0.068
Mean annual ratio of dayly UV/G	0.059	0.068

Citation: Pashiardis S, Kalogirou SA and Pelengaris A. Statistical Analysis and Inter-Comparison of Solar UV and Global Radiation for Athalassa and Larnaca,Cyprus. SM J Biometrics Biostat. 2017; 2(2): 1012.

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 UV irradiance and daily UV 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 UV radiation exceeds the value of 1800 kJ m^{-2} at Athalassa and 2200 kJ m^{-2} at Larnaca. The accumulated UV irradiation received in an average year is 398.4 MJ m^{-2} for Athalassa and 494.4 MJ m^{-2} for Larnaca, which are similar to those in Israel, but much higher than the respective values in other Mediterranean sites.

Regarding the hourly mean values, UV irradiance fluctuates between 22.7 W m^{-2} in December and 59.6 W m^{-2} in July at solar noon at Athalassa. The values at Larnaca are slightly higher than in Athalassa and they fluctuate between 29 Wm^{-2} in December and 71 W m^{-2} in July at solar noon.

For the whole period of measurements the following linear relationships have been obtained for both stations for the hourly and daily values:

Athalassa: $UV_h = 0.059 * G_h$ and $UV_d = 0.059 * G_d$

Larnaca: $UV_h = 0.068 * G_h$ and $UV_d = 0.068 * G_d$

The above relationships indicate that UVT irradiation corresponds to 5.9% and 6.8% of the horizontal global solar irradiation. These values are much higher than those obtained in other regions. Bilbao et al. [29] reported a value of 4.2% in Valladolid, Spain. Martinez-Lozano et al. [52] found slightly lower values (3.3%) in Valencia, Spain. Similarly, Jacovides et al. [17] reported values around 3.3% for Athalassa for the year 2004, while Koronakis et al. [33] found a value of 4.1% for Athens.

Relations of the form: $UVT = a * G^b$ have been also established with the monthly values of 'a' ranging between 0.026 and 0.098, with the lowest ones occurring in the summer and the highest values occurring in winter. The coefficient 'b' ranges between 0.896 and 1.129 with the highest values in the summer period. Slight different values were obtained in other Mediterranean sites.

Empirical relationships were also established with the optical air mass for three different categories of days based on the definition of the clearness index. For the estimation of UV irradiance four empirical models obtained from the literature were tested with data from Athalassa. Murillo's and Barbero's models performed well. By recalibration the Murillo's and Barbero models using data from both stations in Cyprus, the following equations were obtained:

a) Murillo's model

Athalassa: $UV = UV_0 \exp(-0.202 - 0.460\ln(m) + (0.874 - 0.398\ln(m))\ln(k_t))$

Larnaca: $UV = UV_0 \exp(-0.054 - 0.361\ln(m) + (0.883 - 0.305\ln(m))\ln(k_t))$

b) Barbaro's model

Athalassa: $UV = 0.771 * UV_0 * k_t^{0.715} * m^{-0.301}$

Larnaca: $UV = 0.906 * UV_0 * k_t^{0.743} * m^{-0.252}$

The coefficients of the above equations for both stations in Cyprus are almost similar to those obtained in Valladolid (Spain) [28].

Finally, relationships between the clearness index (global hemispherical transmittance) (k_t) and the UV hemispherical transmittance (k_{tUV}) were established. Three different models were implemented. Firstly, a linear fit was applied, without intercept of the form: $k_{tUV} = ak_t$. Secondly, a model of the form: $k_{tUV} = ak_t^b$ was tested and thirdly a quadratic equation is introduced. The annual UV hemispherical transmittance is about 71% of the global hemispherical transmittance. Almost similar values were obtained in Spain [49-50,55]. The highest values occur in the summer months. The coefficient of determinations are close to 1 for both the hourly and daily data.

The dependence of the UV/G ratio values to the solar elevation angle was also examined. This ratio is increased with solar elevation. An increase in UV/G ratio values can be also observed with decreasing of the global hemispherical transmittance (k_t). It can be concluded that the UV hemispherical transmittance is less affected by clouds than the global hemispherical transmittance. Therefore, the presence of clouds reduces less the UV component rather than the global solar radiation, due to the strong absorption of water in the near infrared spectrum. Similar results were obtained by other authors: Jacovides et al. [17]; Foyo-Moreno et al. [55] and Bilbao et al. [29]. This fact can be explained by the diffuse component of UV radiation which increases when cloudiness increases [36].

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 UV radiation than Athalassa.

Nomenclature

A_s	Skewness coefficient
CDF	Cumulative probability density function
CV	Coefficient of variation (%)
G	Global solar irradiance [Wm^{-2}]
G_h	hourly global solar irradiance [Wm^{-2}]
G_0	Extraterrestrial irradiance [Wm^{-2}]
G_{0d}	Daily extraterrestrial irradiation (ETR) [MJm^{-2}]
G_d	Daily global irradiation [MJm^{-2}]
G_{sc}	Solar constant [1366.1Wm^{-2}]
IQR	Inter quartile range
K	Kurtosis
k_t	Hourly clearness index ($k_t = G / G_0$)
k_{tUV}	Hourly UV clearness index ($k_{tUV} = UV / UV_0$)
K_T	Daily clearness index ($K_T = G_d / G_{0d}$)
K_{TUV}	Daily UV clearness index ($K_{TUV} = UV_d / UV_{0d}$)

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m	Optical air mass
Max	Maximum
Min	Minimum
N	Non missing observations
N^*	Missing observations
n	number of data
P_5	Percentile 5%
P_{95}	Percentile 95%
$Q1$	First Quartile
$Q3$	Third Quartile
R^2	Coefficient of determination
$StDev$	Standard deviation
TOC	Total ozone column
UVA	UVA irradiance [Wm^{-2}] / UVA irradiation [kJm^{-2}]
UVA_d	Daily UVA irradiation [kJ m^{-2}]
UVB	UVB irradiance [Wm^{-2}] / UVB irradiation [kJm^{-2}]
UVB_d	Daily UVB irradiation [kJ m^{-2}]
UVC	Ultraviolet radiation in the range of 100 to 280 nm
$UVER$	UV erythema irradiance [Wm^{-2}] / UV erythema irradiation [kJ m^{-2}]
UV	UV irradiance [Wm^{-2}] / UV irradiation [kJ m^{-2}] (UV (A+B))
UVR	UV radiation
UVT	Total UV radiation
UV_0	Extraterrestrial UV irradiance [Wm^{-2}]
UV_h	Hourly UV irradiance [Wm^{-2}]/ Hourly UV irradiation [kJ m^{-2}]
UV_p	Potential UV irradiance [Wm^{-2}]
UV_d	Daily UV irradiation [kJ m^{-2}]
UV_{sc}	Solar constant of UV irradiance [80.83 Wm^{-2}]

Greek:

θ_z	Solar zenith angle (SZA) [degrees]
δ	Solar declination [degrees]
ε	eccentricity correction
φ	Latitude [degrees]
ω	Hour angle [degrees]

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