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Inter-comparison of the solar UVB, UVA and global radiation clearness and UV indices for Beer Sheva and Neve Zohar (Dead Sea), Israel

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Abstract

An inter-comparison of the clearness indices for the solar UVB, UVA and global radiation for Beer Sheva and Neve Zohar (Dead Sea) are presented utilizing radiation data measured from January 1995 through December 2001 for which there is a one-to-one correspondence between the measurements, viz., any day for which a hourly value for one of the sites was missing is rejected and not included in the analysis for that particular radiation type. Beer Sheva is located ca. 65 km to the west and is approximately 700 m above Neve Zohar, which is located on the western shore of the Dead Sea. The Dead Sea is the lowest terrestrial point on the earth, approximately 400 m below mean sea level. The relative magnitudes of the global, UVB and UVA radiation intensities at the two sites can be attributed to the enhanced scattering at the Dead Sea due to the longer optical path length the solar radiation must traverse at the Dead Sea. The degree of attenuation due to scattering phenomena is inversely proportional to the wavelength raised to some power and, consequently, it is greatest for UVB and very small for global radiation. The UVB and UVA solar constants were determined from the extraterrestrial radiation values tabulated by Fröhlich and Wehrli [Spectral distribution of solar irradiance from 25000 nm to 250nm, in: M. Iqbal, An introduction to solar radiation, Academic Press, New York, 1981, Appendix C, pp. 380–381]. The clearness indices for global and UVA radiation were of similar magnitude, whereas those for UVB radiation were of two orders of magnitude smaller. In addition, the monthly average hourly UV Index at both sites has also been determined and an inter-comparison of the values has been performed for all available hourly values from January 1995 through August 2002 for both sites. It is observed that the monthly average hourly UV Index values at the Dead Sea are never in the extreme range.
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1. Introduction

In recent years, there has been growing interest in the monitoring of terrestrial solar ultraviolet radiation due to the increasing evidence of global depletion of stratospheric ozone. Any reduction in the thickness of the stratospheric ozone layer will result in an increase in the ultraviolet radiation intensity reaching the earth's lower atmosphere and incident on its surface. Ultraviolet radiation affects many chemical and biological processes and any increase in the radiation intensity is of concern, because of the potential deleterious effects on the biosphere, tropospheric air quality and on materials such as wood and polymers. The Dead Sea is a salt lake located between Israel and Jordan. It is one of the saltiest bodies of water known (345 g mineral salts per liter) and is situated at the lowest terrestrial point on earth, about 400 m below mean sea level. The solar radiation intensity at the Dead Sea is of interest due to the uniqueness of this site. Stanhill [2,3] and Stanhill and Ianetz [4] have reported upon global radiation intensity measurements at the Dead Sea basin. Kudish et al. [5,6] have reported upon ultraviolet, both UVB and UVA, and global radiation measurements at the Dead Sea. These ultraviolet radiation measurements are of special interest since the Dead Sea region is an internationally recognized climatotherapy center for the treatment of psoriasis, atopic dermatitis, vitiligo and other skin and rheumatic diseases (cf. [7–10]).

Kudish et al. [5] studied the relative attenuation of the UVB and UVA radiation intensities between the Neve Zohar (located in the Dead Sea basin) and Beer Sheva. The Beer Sheva site is located ca. 65 km to the west of and is approximately 700 m above the Dead Sea. The results of the study showed that the ultraviolet radiation measured at the Dead Sea was attenuated relative to that measured at Beer Sheva. The UVB radiation was attenuated to a much greater degree than the UVA radiation. The attenuation of solar radiation caused by scattering by air molecules, water vapor and aerosols has been the subject of numerous studies and approximate correlations have been developed to estimate the magnitude of the effect (cf. [11,12]). Air molecules are small compared with the wavelengths (λ) of the radiation significant in the solar spectrum. Consequently, the scattering of solar radiation by air molecules is in accordance with the theory of Rayleigh, which predicts that the degree of scattering varies approximately as λ^{-4}. The scattering of solar radiation by water molecules is a function of the amount of precipitable water (the amount of water vapor in the air column above the observation site) and an empirical scattering coefficient for water vapor that varies as λ^{-2} has been proposed. Moon [11] developed an empirical scattering coefficient for aerosols, which varies approximately with $\lambda^{-0.75}$. In all cases, the degree of attenuation by the three scattering phenomena is an inverse function of wavelength. Bener [13], Reiter et al. [14], Blumthaler [15] and Piazena [16] have reported similar findings for the attenuation of ultraviolet radiation intensity with decreasing altitude in the Alps and Andes mountains and that the UVB is attenuated much more than the UVA.

It should be noted that the absorption of solar radiation in the atmosphere is due mainly to ozone in the ultraviolet range and water vapor, in specific bands in the infrared range ($\lambda > 780$ nm) of the solar spectrum. Three types of ultraviolet radiation have been defined as a function of their wavelength range: (i) UVC, with a spectral range from 100 to 280 nm, which is completely absorbed by the stratospheric ozone layer, (ii) UVB, with a spectral range from 280 to 320 nm, which is mostly absorbed by the stratospheric ozone layer and virtually no solar radiation below 290 nm is incident on the Earth's surface, (iii) UVA, with a spectral range from 320 to 400 nm, where stratospheric ozone layer absorption is minimal. Ozone absorption decreases with increasing λ and above 350 nm there is no absorption. There is, also, a weak ozone absorption band in the visible range ($380 < \lambda < 780$ nm) of the solar spectrum, at about 600 nm.

Kudish and Evseev [6] have analyzed the data from Neve Zohar and Beer Sheva to determine if the ultraviolet radiation could be correlated with the global radiation both on a monthly and a seasonal basis. They had a much broader database available than in the abovementioned publication, viz. [5], as a result of the ensuing time interval. Their analysis was based upon 7 years of measurements, whereas the first publication was based upon only 2 years of measurements. It was observed that the hourly global and UVA radiation at both sites were highly correlated. In the case of the UVB radiation, the correlations were found to be poor. This is not unexpected, since the UVB radiation is attenuated significantly by the scattering phenomena, whereas the global radiation is attenuated by to a much lesser degree. The good correlations between UVA and global radiation are explained by the fact that the UVA radiation is affected by the scattering phenomena to a much lesser degree than the UVB.

In the present study, we have extended our analysis of the data for these two sites beyond the inter-comparison of the ultraviolet radiation intensities, i.e., relative attenuations, and spectral selectivity of the attenuation processes as presented in Kudish et al. [5]. We have based the inter-comparison of the ultraviolet radiation databases on the concept of clearness index. We have used the extraterrestrial UVB and UVA radiation as tabulated by Fröhlich and Wehrli [1] to calculate daily clearness indices for both types of ultraviolet radiation. Martínez-Lozano et al. [17,18] have used a total UV clearness index to analyze the data for Valencia, Spain, based upon the same tabulated values.

In recent years, the improvements in the quality of life of the people living in the developed countries have changed their behavioral patterns to a significant degree. They now have much more free time for recreation and vacations, which, in general, translates to an increased exposure to solar radiation and its UV components with increasing availability of outdoor leisure time. This is especially so with regard to vacations, the majority of which are taken in regions having relatively high UV radiation environments. These two factors, viz., the enhanced UV radiation intensity due to global depletion of stratospheric ozone and the increased cumulative sun exposure of the public, are of major concern due to the deleterious health-associated effects of increased exposure to UV radiation.

The solar UVB, or erythemal UV, radiation is most sensitive to the changes in the total ozone content of the atmosphere. It is generally assumed that an increase in UVB radiation at the earth's surface would be detrimental to the well being of both plant and animal life. The problems of increased sunburn, skin cancer (melanoma and non-melanoma) and eye diseases (cataracts, melanoma) are usually emphasized for humans, while the general destruction of plant tissue and living cells are also being investigated. The annual growth rate of the incidence of malignant melanoma cases has been estimated at 4%, since 1973 ACS [19]. The harmful effects of exposure to UVB radiation are partially compensated for by some beneficial factors, which include germicidal action, the production of vitamin D for the prevention of rickets and the photoclimatherapy treatment of various skin diseases such as psoriasis, atopic dermatitis and vitiligo.

The health-associated effects of UVA exposure include photo-ageing of the skin, immunosuppression of the skin immune system and potential enhancement of the negative effects of UVB exposure. The treatment of psoriasis by UVA radiation in conjunction with psoralen (PUVA) has also been widely used in the past but has recently come under scrutiny as potentially increasing the risk of cancer [20].

In view of the above, atmospheric scientists and medical practitioners have become aware of the necessity of generating public awareness to the dangers of excessive exposure to solar radiation. Their task was to present the UVB radiation intensities on a scale that could be easily translated by the public-at-large to suggested maximum time intervals for sun exposure or, more important, when to avoid sun exposure. The solution was the development of an ultraviolet index for informing the general public, through the media, of the levels of the UV radiation, which is intended to help them plan their outdoor activities such as to prevent overexposure to solar radiation. This index is based upon the erythemal action of the UVB, but both the scale and index name were defined in a number of ways by different countries where it was utilized to inform the general public. The necessity of arriving at a universally accepted UV Index was recognized and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) in collaboration with the WHO, WMO and UNEP has produced recommendations for defining such an index. They referred to it as the "UV Index" (UVI) and it is determined from the integrated erythemally weighted radiation to all wavelengths up to 400 nm, in units of W m^{-2}, i.e., the measured UV irradiating flux in the UV spectral range is weighted by the erythema action spectra [21], multiplied by 40.

Martínez-Lozano et al. [22] reported on their measurements of the UVI at two locations on the Spanish Mediterranean coast during 2000, where a large proportion of summer tourism of the country is concentrated. They recorded the UV radiation at half hour intervals. They found that the UVI achieved a value of 10 on only three occasions but a value of 9 was reached repeatedly during the summer. In a more recent publication, Martínez-Lozano et al. [23] reported on the UVI measured during the years 2000 and 2001 at 16 stations comprising the Spanish broadband UVB radiometric network. They found that the maximum UVI values during the summer were around 9, though they frequently exceeded this value at the inland measurement stations. The WHO classifies UVI values of 9 or greater as extreme risk (only integer values are used in reporting the UVI). They also observed that, in 90% of the cases, the maximum daily value of the UVI deviates from that at solar noon by at most one unit. A difference of a single unit in the UVI corresponds to a difference of 0.025 W m^{-2} in the ultraviolet erythema radiation intensity. Consequently, they suggested that it would be acceptable to determine the UVI based upon solar noon in the absence of experimental values for the maximum daily erythema radiation intensity.

It was the need to provide the dermatologists of the medical spas located in the Dead Sea region with both an ultraviolet database and on-line radiation intensities values that gave the impetus for these measurements. The goal of the research was to optimize the photoclimatherapy treatment protocol by minimizing the exposure to solar radiation without sacrificing treatment efficacy. This is being accomplished by correlating the cumulative UVB radiation dose to treatment efficacy (cf. [24]). It is also of interest to analyze these data with respect to the UVI, especially with regard to the popularity of the Dead Sea region as a resort area.

2. Measurements

The radiation data on which this study is based are being monitored at two meteorological stations: one located in the Dead Sea basin at Neve Zohar; and the other in Beer Sheva, on the campus of the Ben-Gurion University of the Negev. Neve Zohar is situated in the Judean desert and is on the western shore of the Dead Sea. Beer Sheva is located in the southern Negev region of Israel, a semi-arid zone, at a distance of ca 65 km to the west of the Dead Sea and situated at 315 m above mean sea level. The site parameters for the two stations are listed in Table 1. The instrumentation utilized to measure the UV radiation at both sites is identical and consists of a Solar Light Co. Inc., Model 501A UV-Biometer for the measurement of UVB and a Solar Light Co. Inc., analog UVA version of Model 501A UV-Biometer for the measurement of UVA. The global radiation is measured by a Kpipp & Zone, Model CM11, at Neve Zohar and by an Eppley, Model PSP, at Beer Sheva.

A Campbell Scientific Instruments data-logger, located at each site (a Model CR21 at Neve Zohar and a Model CR10 at Beer Sheva), monitors and stores the data at 10-min intervals (i.e., the meters are scanned at 10 s intervals and average values at 10-min intervals are calculated and stored). The data are downloaded via modem periodically from the data-loggers to a desktop computer in Beer Sheva.

The UVB and UVA measurements were initiated at Neve Zohar in February 1995 and the radiation has been monitored continuously except for interruptions; both scheduled to enable annual factory calibration checks (the meters also undergo, at this time, side-by-side inter-comparisons) and random ones caused by power failures. The UVB measurements were inaugurated at the Beer Sheva site in May 1994 and that for UVA in June 1995 and have been monitored continuously except for the abovementioned interruptions. The global radiation measurements were initiated at Neve Zohar in January 1995, whereas in Beer Sheva the global radiation has been continuously monitored since September 1976. The global radiation instruments undergo annual field calibration checks by the Israel Meteorological staff using an absolute standard. These two meteorological stations are part of the national network of meteorological stations and are connected via modem to the Israel Meteorological Service, located at Bet Dagan.

The Model 501A UV-Biometer measures UVB radiation in units of Minimum Erythema Dose per Hour (MED/H). This unit is calculated by the cross-multiplication of the irradiating flux in the UVB spectral range and the Erythema Action spectra (cf. [21]). Consequently, the UVB biometer has a spectral response normalized to that at 297 nm (i.e., the normalized spectral response at 297 nm is equal to unity) and the logarithm of the normalized spectral response degrades linearly with wavelength and is ~0.01 at 320 nm and ~0.001 at 330 nm. One MED/H is defined as that dose which causes minimal redness of the average skin type 2 after 1 h of irradiation. The effective power of 1 MED/H is equivalent to 0.0583 W m^{-2} for an MED of

Table 1
Site parameters for the two meteorological stations

Site	Latitude	Longitude	Altitude (m m.s.l.)
Neve Zohar	31°12′ N	35°22′ E	−375
Beer Sheva	31°15′ N	34°45′ E	+315

21 mJ cm^{-2}. This effective power of 1 MED was utilized to convert the measured UVB radiation to W m^{-2} when calculating the corresponding clearness and UV Index. The accuracy of the measurement is ±5% for the daily total.

The analog UVA version of Model 501A UV-Biometer measures the irradiating flux in the UVA spectral range in units of W m^{-2}. The relative spectral response is normalized to that at ~370 nm and is >0.2 in the range of 320 nm $\leq \lambda \leq$ 390 nm; decreasing rapidly outside this range. The accuracy of the measurement is also ±5% for the daily total.

The individual databases have undergone an extensive analysis to give statistical evidence to the correctness of the calculated monthly average daily values. This was done by determining the coefficient of autocorrelation function and then using these values to determine the standard errors of both the monthly average daily values and the monthly average daily standard deviations. It was determined that the standard errors are less than the inherent measurement for all instruments in this study. Consequently, the monthly average daily and hourly radiation intensities are representative of the two sites (cf. [25]).

3. Data analysis and results

3.1. Clearness indices

The database utilized in this study consists of essentially six independent databases, viz., a set of three databases corresponding to global, UVB and UVA for each site, containing hourly measurements from January 1995 through December 2001. The databases for each type of radiation were then narrowed to include only those days for which a one-to-one correspondence between measurements at each site existed, i.e., any day for which a hourly value for one of the sites was missing is rejected, only for that particular radiation type, and not included in the analysis for that particular radiation type. Consequently, the number of days for each month varies from one type of radiation to another.

The daily clearness indices for the UVB and UVA radiation are defined in the same manner as that used for global radiation, i.e., the ratio of daily radiation on a horizontal surface to the corresponding extraterrestrial radiation. The extraterrestrial global radiation was calculated using the accepted solar constant value, viz., $I_{SC} = 1367$ W m^{-2}. The solar constants corresponding to extraterrestrial UVB and UVA radiation were determined from the Fröhlich and Wehrli [1] tabulated values, corresponding to the wavelength range of the UVB and UVA meters utilized in this study. The ultraviolet solar constants values used in this analysis are as follows:

i. UVB solar constant-$I_{SC\text{-}UVB} = 19.02$ W m^{-2} for 290 nm $\leq \lambda \leq$ 320 nm.
ii. UVA solar constant-$I_{SC\text{-}UVA} = 70.64$ W m^{-2} for 320 nm $\leq \lambda \leq$ 390 nm.

The hourly UVB radiation values, which are measured by the meter in units of MED/H, were first converted to W m^{-2} using the effective power of 1 MED prior to calculating the corresponding clearness index.

The results of the analysis of the six databases are reported as monthly average daily radiation, coefficient of variation (reported as a percentage, Cv), mean and median clearness indices for global, UVB and UVA radiation at both sites (cf. Tables 2–4). The number of days within

Table 2
Monthly average daily global radiation, percent coefficient of variation, mean and median clearness indices for Neve Zohar and Beer Sheva

Month (days)	Neve Zohar				Beer Sheva			
	Global radiation (Wh m^{-2})	Coefficient of variation (%)	K_T mean	K_T median	Global radiation (Wh m^{-2})	Coefficient of variation (%)	K_T mean	K_T median
J (188)	3164.0	25.6	0.532	0.578	2976.1	25.3	0.518	0.549
F (188)	4088.1	27.6	0.562	0.617	3840.6	26.7	0.539	0.572
M (209)	5277.4	22.4	0.596	0.648	5033.0	24.0	0.575	0.618
A (191)	6402.6	18.8	0.621	0.665	6255.7	19.6	0.610	0.646
M (212)	7407.9	13.5	0.660	0.686	7348.0	12.2	0.659	0.686
J (201)	8056.8	4.7	0.705	0.708	7955.6	4.7	0.695	0.702
J (211)	7617.8	5.5	0.678	0.686	7637.0	5.4	0.678	0.684
A (191)	7103.9	4.2	0.673	0.675	7052.9	5.1	0.670	0.675
S (201)	6169.9	6.7	0.662	0.667	6053.2	7.8	0.656	0.662
O (215)	4837.1	13.8	0.630	0.647	4639.9	15.0	0.613	0.638
N (208)	3692.5	16.0	0.588	0.609	3515.8	16.9	0.575	0.605
D (214)	2917.7	25.0	0.527	0.580	2857.9	22.7	0.535	0.585

Table 3
Monthly average daily UVB radiation, percent coefficient of variation, mean and median clearness indices for Neve Zohar and Beer Sheva

Month (days)	Neve Zohar				Beer Sheva			
	UVB radiation (MED)	Coefficient of variation (%)	$K_{TUVB} \times 10^2$ mean	$K_{TUVB} \times 10^2$ median	UVB radiation (MED)	Coefficient of variation (%)	$K_{TUVB} \times 10^2$ mean	$K_{TUVB} \times 10^2$ median
J (124)	5.61	26.8	0.403	0.421	5.85	29.0	0.429	0.441
F (117)	8.68	33.2	0.501	0.543	9.24	32.9	0.544	0.566
M (198)	12.26	27.4	0.581	0.600	13.53	28.7	0.647	0.684
A (194)	16.16	24.5	0.658	0.690	18.29	24.4	0.748	0.779
M (210)	19.82	18.1	0.747	0.759	23.51	16.5	0.885	0.915
J (201)	22.80	10.2	0.836	0.839	26.75	7.2	0.978	0.979
J (210)	21.44	11.6	0.800	0.811	25.49	8.7	0.949	0.968
A (185)	19.26	10.6	0.762	0.745	22.74	9.0	0.904	0.909
S (133)	15.58	11.6	0.697	0.692	18.28	10.7	0.832	0.834
O (164)	10.78	18.1	0.593	0.602	12.55	18.7	0.703	0.720
N (125)	7.00	18.1	0.466	0.472	8.41	20.1	0.526	0.536
D (96)	5.03	23.8	0.378	0.400	5.44	22.7	0.422	0.445

Table 4
Monthly average daily UVA radiation, percent coefficient of variation, mean and median clearness indices for Neve Zohar and Beer Sheva

Month (days)	Neve Zohar				Beer Sheva			
	UVA radiation (Wh m^{-2})	Coefficient of variation (%)	K_{TUVA} mean	K_{TUVA} median	UVA radiation (Wh m^{-2})	Coefficient of variation (%)	K_{TUVA} mean	K_{TUVA} median
J (150)	140.31	22.4	0.461	0.493	141.41	24.7	0.479	0.515
F (104)	187.11	28.7	0.500	0.567	192.35	27.4	0.526	0.582
M (175)	246.55	22.2	0.537	0.571	250.24	23.9	0.552	0.589
A (167)	303.50	18.4	0.572	0.604	313.35	18.9	0.593	0.626
M (175)	352.74	14.6	0.612	0.638	371.82	13.6	0.644	0.670
J (185)	388.53	4.7	0.658	0.663	407.46	4.6	0.688	0.693
J (210)	366.46	6.2	0.631	0.639	389.12	6.2	0.669	0.675
A (194)	342.32	5.2	0.628	0.628	357.50	5.6	0.658	0.657
S (179)	292.32	8.3	0.609	0.613	304.04	8.0	0.639	0.646
O (217)	220.40	13.8	0.554	0.566	230.85	14.6	0.591	0.610
N (200)	165.30	15.2	0.509	0.522	171.49	15.7	0.543	0.561
D (148)	131.14	21.0	0.459	0.494	136.15	21.7	0.492	0.525

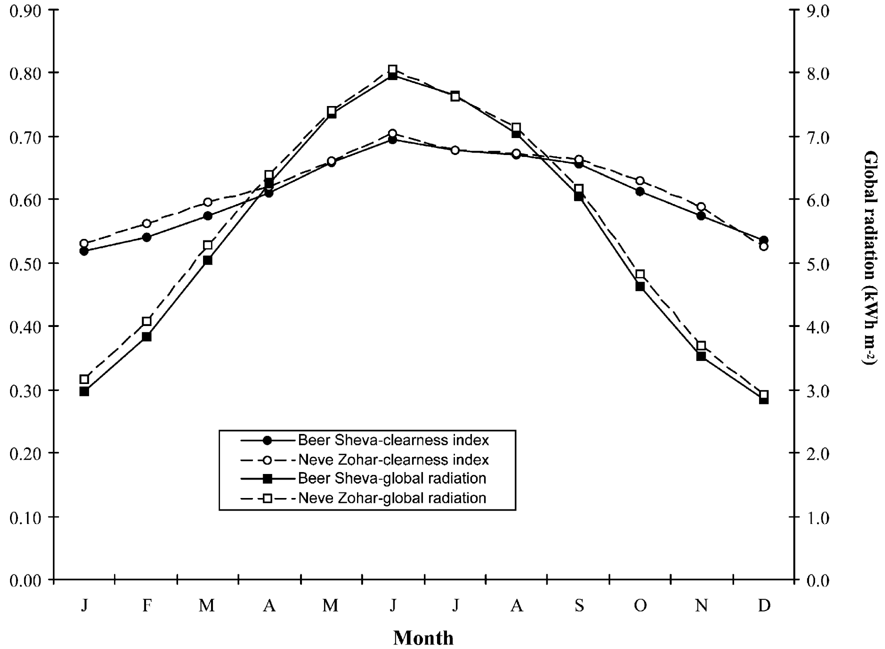

Fig. 1. Monthly average daily global radiation and clearness index, K_T.

each monthly database is reported within the parentheses in column 1 of the tables. The coefficient of variation, which is defined as the ratio of the standard deviation to the mean value, gives an indication of the dispersion of the values, whereas the difference between the mean and median values gives an indication of the degree of symmetry of the distribution around the mean value within an individual database. In addition, the monthly average daily radiation and clearness indices values at both sites for the three radiation types are also presented graphically in Figs. 1–3 to facilitate an inter-comparison.

3.2. UV Index

The database utilized in this analysis consists of all available hourly values for UVB radiation from January 1995 through August 2002 for both sites. The hourly UVB radiation values were first converted to W m^{-2} and then multiplied by 40 to determine the corresponding UVI values. The monthly average hourly UVI values throughout the day are reported in Figs. 4 and 5 for Neve Zohar and Beer Sheva, respectively. The UVI values on the ordinates have been separated into four ranges according to the generally accepted classification of the UVI values, viz., extreme ≥ 9; $7 <$ high < 9; $4 <$ moderate < 7 and low < 4 (a UVI < 2 is considered negligible). In terms of sun exposure time to achieve incipient redness of a type 2 skin (sometimes burns, sometime tans), these four ranges of UVI values translate into <15, 20, 30 min and more than 1 h, respectively.

The monthly average midday hourly UVI values for Neve Zohar (NZ) and Beer Sheva (BS) are reported in Table 5. The midday hours are defined as between 10:00 and 14:00 Israel

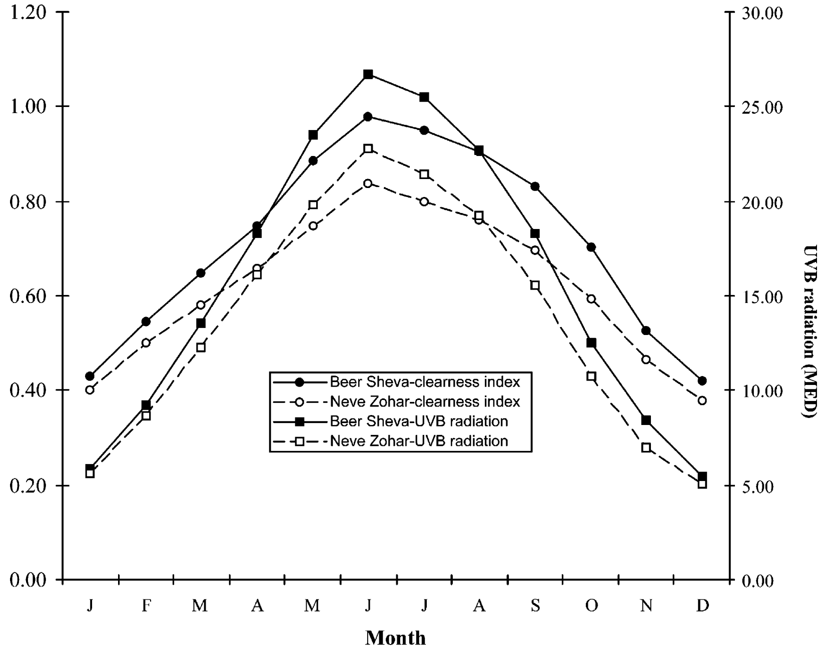

Fig. 2. Monthly average daily UVB radiation and clearness index, K_{TUVB}.

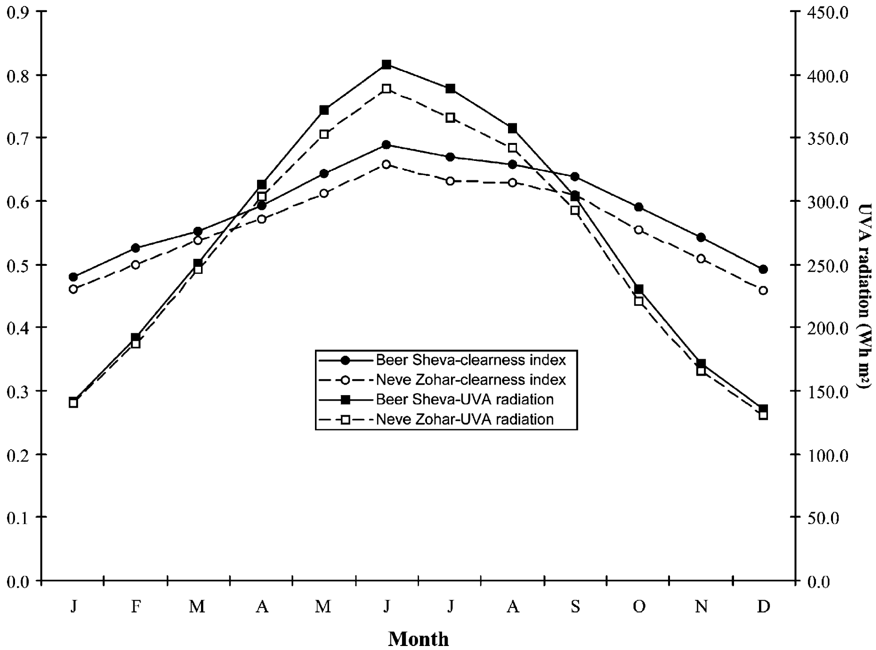

Fig. 3. Monthly average daily UVA radiation and clearness index, K_{TUVA}.

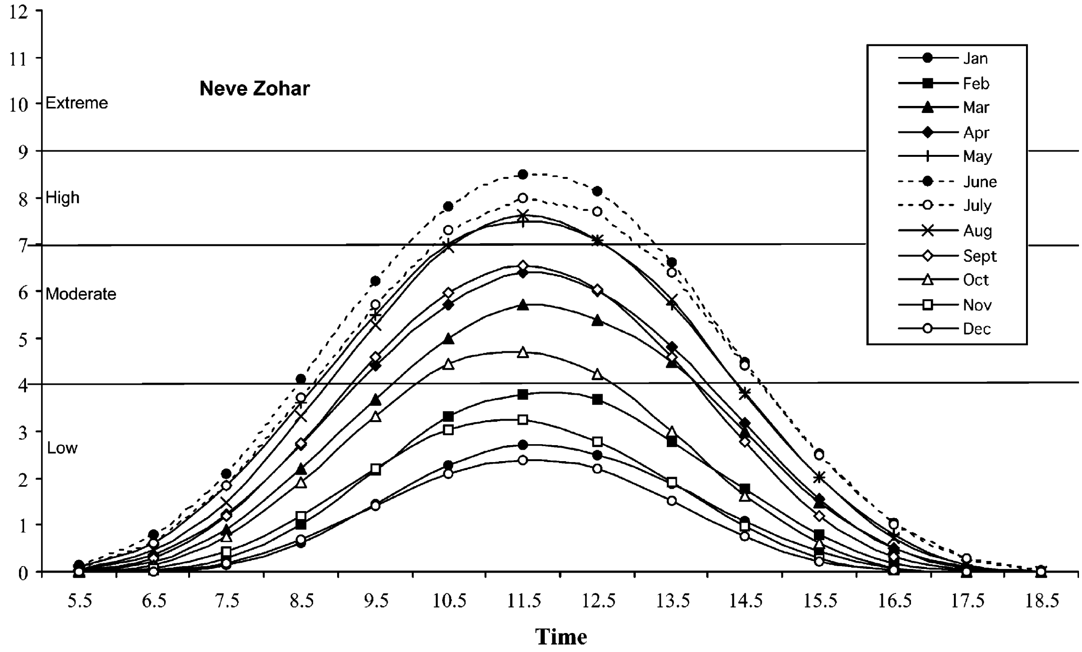

Fig. 4. Monthly average hourly UVI values for Neve Zohar.

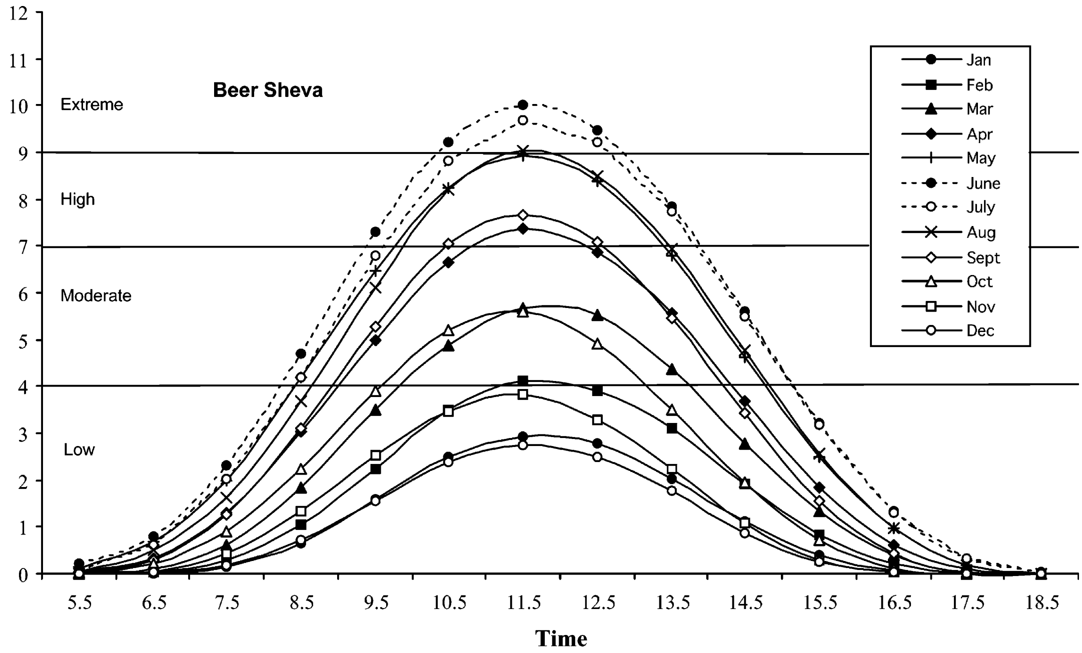

Fig. 5. Monthly average hourly UVI values for Beer Sheva.

Table 5
Monthly average midday hourly UVI for Neve Zohar and Beer Sheva

Month $\Delta\lambda$[a]	Site (h)	10–11	11–12	12–13	13–14
January	NZ (174)	2.3 (27%)[b]	2.7 (29%)	2.5 (33%)	1.9 (33%)
10 min	BS (210)	2.5 (30%)	2.9 (35%)	2.8 (35%)	2.0 (37%)
February	NZ (151)	3.3 (30%)	3.8 (32%)	3.7 (35%)	2.8 (37%)
9 min	BS (196)	3.5 (32%)	4.1 (33%)	3.9 (36%)	3.1 (35%)
March	NZ (241)	5.0 (39%)	5.7 (39%)	5.4 (40%)	4.5 (43%)
10 min	BS (244)	4.9 (34%)	5.7 (32%)	5.5 (31%)	4.4 (32%)
April	NZ (240)	5.7 (29%)	6.4 (26%)	6.0 (27%)	4.8 (26%)
19 min	BS (227)	6.6 (26%)	7.4 (26%)	6.9 (27%)	5.5 (27%)
May	NZ (248)	7.0 (19%)	7.5 (20%)	7.1 (20%)	5.7 (20%)
23 min	BS (247)	8.2 (17%)	**8.9 (18%)**[c]	8.4 (16%)	6.8 (19%)
June	NZ (240)	7.8 (11%)	**8.5 (11%)**	8.1 (11%)	6.6 (11%)
29 min	BS (235)	**9.2 (8%)**	**10.0 (7%)**	**9.5 (7%)**	7.8 (8%)
July	NZ (247)	7.3 (12%)	8.0 (12%)	7.7 (12%)	6.4 (12%)
23 min	BS (248)	**8.8 (8%)**	**9.7 (9%)**	**9.2 (10%)**	7.7 (8%)
August	NZ (248)	6.9 (11%)	7.6 (11%)	7.1±1 (1%)	5.8 (13%)
15 min	BS (228)	8.2 (9%)	**9.0 (9%)**	**8.5 (9%)**	6.9 (11%)
September	NZ (180)	6.0 (11%)	6.5 (11%)	6.0 (11%)	4.6 (13%)
23 min	BS (196)	7.0 (9%)	7.7 (10%)	7.1 (11%)	5.5 (13%)
October	NZ (217)	4.4 (18%)	4.7 (19%)	4.2 (19%)	3.0 (21%)
33 min	BS (202)	5.2 (18%)	5.6 (19%)	4.9 (22%)	3.5 (23%)
November	NZ (191)	3.0 (20%)	3.3 (20%)	2.8 (20%)	1.9 (21%)
35 min	BS (162)	3.5 (20%)	3.8 (19%)	3.3 (21%)	2.2 (23%)
December	NZ (133)	2.1 (27%)	2.4 (27%)	2.2 (25%)	1.5 (26%)
24 min	BS (113)	2.4 (28%)	2.8 (25%)	2.5 (26%)	1.8 (23%)

[a] Difference between solar and local standard time on 15th day of the month.
[b] Coefficient of variation of the average hourly UVI values.
[c] UVI values in the extreme range, i.e., integer values ≥ 9, are presented in boldface type.

Standard Time. The number of hourly measurements in each individual monthly database is cited in column 2 within parentheses after the station name. The coefficient of variation is reported together with the corresponding UVI value. We have departed from standard convention for reporting UVI values in integers in order to emphasize the differences in the hourly values at the two sites. In addition, the table includes the difference between solar and local standard time on the 15th day of each month. It is observed from the table that the local standard time lags behind solar time throughout the year (the actual minimum and maximum values are 5 min from February 3–24 and 36 min from October 30 through November 8, respectively). We have limited this analysis to the peak solar radiation time interval, i.e., 10–14, since this is the time interval most relevant with regard to solar exposure. All the hourly data refer to Israel Standard Time (GMT + 2), since the UVI is intended to provide information to the public-at-large.

4. Discussion

4.1. Global radiation

The magnitudes of the monthly average daily global, UVB and UVA radiation intensities reported in Tables 2–4 for the two sites are similar to those reported previously by Kudish et al. [5,6]. The small variation in individual values is due to the different, broader, database utilized in this study.

The magnitude of the monthly average daily global radiation intensity at both sites is similar. The global radiation intensity ratio of Neve Zohar to Beer Sheva exceeds 1.05 for only 2 months, January and February, where it is 1.06. It is $\leq$1.02 from April through September. The occurrence of ratio values $\geq$1.05 is most likely due to differences in local climatic conditions, i.e., the clouds move eastward from Beer Sheva and may be broken up as they pass over the Judean mountains prior to reaching the Dead Sea basin and Neve Zohar, since attenuation of global radiation due the difference in altitude between the two sites by scattering phenomena is negligible. The coefficients of variation values for the individual months are of similar magnitudes at the two sites. They are less than 10%, from June through September and greater than 20% from November through March. This reflects the relatively narrow distribution of the daily global radiation intensities observed during the summer months and, in contrast, the variability observed during the winter months.

The monthly average daily clearness index values, K_T, at both sites always exceed 0.5 and from May through September they are greater than 0.65, viz., indicating clear days. It is also observed that all the monthly median values at both sites are greater than the mean values. This indicates that more than 50% of individual daily values are greater than the corresponding monthly mean value. The difference between the median and mean values for the months June through September is $<$0.08. This observation, together with the previously noted relatively low coefficient of variation values, indicates the relative stability of the daily global radiation intensity during these months and prevalence of clear days.

4.2. UVB radiation

The relative magnitude of the monthly average UVB radiation intensities at the two sites is mainly a result of their difference in altitude and the resultant enhanced scattering due the longer optical path length for the solar radiation incident at the Dead Sea basin. It should be noted that the aerosol loadings at both sites are of similar magnitudes based upon sporadic measurements using a Microtops II Ozone Monitor & Sun Photometer, Solar Light Co., Inc., which measures aerosol optical depth made at 1020 nm [26]. The monthly variation in the relative attenuation, especially during the winter months, is probably due to the local climatic conditions mentioned previously with regard to global radiation. The UVB radiation intensity ratio of Neve Zohar to Beer Sheva varies between 0.83 and 0.88 during the months April through November and between 0.91 and 0.96 from December through March. The monthly coefficients of variation values at both sites are greater than the corresponding values for the global radiation. The monthly coefficients of variation values are $<$10% for only June through

August in Beer Sheva. They exceed 20% from December through April for Neve Zohar and from November through April in Beer Sheva.

The monthly average daily UVB clearness index, K_{TUVB}, values are two orders of magnitude less than corresponding values for both global and UVA radiation. This is the result of the very high attenuation of UVB radiation by stratospheric ozone and the scattering phenomena. In fact, almost no UVB radiation with a $\lambda < 295$ nm is incident upon the earth's surface. The much greater degree of attenuation of the UVB relative to the global radiation is evidenced by the fact that the ratio of the annual daily average of the radiation intensities of UVB to global is of the order of 0.03%, whereas the ratio of the respective solar constants, $I_{SC\text{-}UVB}/I_{SC}$, is 1.21%. The monthly average daily K_{TUVB} values are lowest from November through January at both sites. The lowest values are observed in December, i.e., 0.378×10^{-2} and 0.422×10^{-2} for Neve Zohar and Beer Sheva, respectively. The lower K_{UVB} values during these months are not unexpected and can be attributed, in part, to the fact that the solar altitude is lower during these months, which results in a longer optical path length. Also, this behavior is also observed for both global and UBA radiation. It is also affected by local climatic conditions.

Once again, it is observed that all the monthly median values, with the exception of August and September at Neve Zohar, are greater than the mean values. In addition, the two values are essentially identical during June at Beer Sheva. The difference between the median and mean values for the months June, October and November is <0.09 at Neve Zohar. In the case of Beer Sheva, the two values are essentially identical for June and September and is 0.05 for August. These observations indicate that the daily UVB radiation intensities during a month vary to a greater extent than the corresponding global radiation but, nevertheless, more than 50% of individual daily values are greater than the corresponding monthly mean value with the exception of the months of August and September at Neve Zohar.

4.3. UVA radiation

The relative magnitude of the monthly average UVA radiation intensities at the two sites are also affected by their difference in altitude but to a much lesser extent than that for the UVB radiation. The variation in the relative magnitude of the average monthly values is, once again, also a function of local climatic conditions. The monthly average daily UVA radiation intensity ratio of Neve Zohar to Beer Sheva varies between 0.94 and 0.99 throughout the year, with a minimum in July and maximum in January. The variation of the monthly coefficient of variation values at both sites is very similar to that for the global radiation. The monthly coefficients of variation values are <10% from June through September at both sites. They exceed 20% from December through March for both sites. The similarity between the observed behavior of the UVA and global radiation intensities gives further credence to the analysis of these data as reported by Kudish and Evseev [6].

The monthly average daily UVA clearness index values, K_{TUVA}, are somewhat lower than the corresponding monthly average daily global radiation, K_T values. This observation can be explained by the fact that the lower wavelengths within the UVA radiation spectrum range, nevertheless, undergo attenuation as a result of scattering phenomena. The monthly average daily K_{TUVA} values exceed 0.5 for all months at both sites with the exception of January and December. The difference between the median and mean values for the months June through

September are <0.08 at both sites, with the exception of month of August at Beer Sheva, i.e., they are essentially identical.

4.4. Global, UVB and UVA radiation

It is observed from the monthly average daily coefficient of variation values reported in Tables 2–4 that a maximum value is observed for the month of February for all radiation types at both sites. A possible explanation for this observation may be the occurrence of a maximum in cloud cover at these sites during the month of February. This is supported by the previously reported observation of a maximum value for the ratio of daily diffuse to daily global radiation, H_d/H, for Beer Sheva (cf. Table 6 in [27]), since this ratio is an indirect indication of cloud cover.

The calculated individual average daily clearness indices for all months within each radiation type database at both sites were also utilized to determine their degree of correlation. The results of this analysis, as expressed by the regression equations, are as follows:

Global radiation (82 months) K_T (Neve Zohar) $= 0.945 K_T$ (Beer Sheva) $+ 0.042$, $R = 0.97$

UVB radiation (77 months) K_{TUVB} (Neve Zohar) $= 0.779 K_{TUVB}$ (Beer Sheva) $+ 0.065$, $R = 0.95$

UVA radiation (74 months) K_{TUVA} (Neve Zohar) $= 0.949 K_{TUVA}$ (Beer Sheva), $R = 0.96$

The correlation coefficients for the regression equations for all three types of clearness indices are relatively high. It is apparent from the regression equations that the global and UVA radiation exhibit very similar behavior, viz., their respective slopes are both very close to unity. On the other hand, the markedly different behavior observed with regard to the UVB radiation, viz., the slope of the linear regression equation, is as expected in view of its much stronger dependence on the optical path length.

4.5. UV Index

It is observed from Fig. 4 that the monthly average hourly UVI values for Neve Zohar are never in the extreme range, despite the fact that the Dead Sea is located in the Judean desert and is well known for its extreme ambient temperatures (e.g., the monthly average maximum ambient temperatures are >35 °C from June through September and >30 °C for May and October) and relatively dry climate. In fact, only during 4 months of the year, viz., May through August, does the UVI enter the high range during the midday hours of 10–13. This is in marked contrast to the findings presented in Fig. 5 for Beer Sheva, located in the semi-arid Negev region, which exhibits UVI values in the extreme range from 10–13 for June and July and 11–12 for May and August. In addition, the UVI is in the high range for June and July from 9 to 10 and 13 to 14, for May and August from 10 to 11 and 12 to 14 and for April and September from 11 to 13. The relatively low UVI values for the Dead Sea region are a result of the fact that the Dead Sea is located at the lowest terrestrial point on the earth and the consequent wavelength selective attenuation of the UVB radiation by the scattering phenomena [5]. The wavelength selective attenuation of the solar radiation by the scattering phenomena is further highlighted by an inter-comparison of the monthly average daily global radiation intensities at the two sites as reported in Table 2, viz., they are of similar magnitudes.

The monthly average midday hourly UVI values for Neve Zohar and Beer Sheva are reported in Table 5. It is observed that from April through October the average hourly UVI values for Beer Sheva are greater than the corresponding values for Neve Zohar by at least a single unit, i.e., when they are rounded off to the nearest integer. In addition, the monthly average hourly UVI values are observed to be asymmetric with regard to noontime, i.e., the magnitudes of the UVI from 10 to 11 and 11 to 12 are greater than those for 13–14 and 12–13, respectively. This asymmetry is also observed in Figs. 4 and 5. This asymmetry is mainly due to the fact that the local standard time lags behind the solar time throughout the year, as is seen for the 15th day of each month as reported in column 1 of Table 5. The time lag between standard time and solar time also explains the observed relatively large differences between the average hourly UVI values for the monthly pairs February–November and March–October after noon Israel standard time (Figs. 4 and 5) i.e., the mid-month time lag for February and March is 9 and 10 min, respectively, whereas for November and October it is 35 and 33 min, respectively.

The scatter of individual hour values around the average value for a particular midday hour database can be approximated by the magnitude of the coefficient of variation. It is observed from Table 5 that the midday average hourly coefficient of variation values can be, more or less, grouped into three sets based upon their magnitude, as follows:

- $\%CV < 15$: June through September
- $15 < \%CV < 25$: May, October and November
- $\%CV > 25$: January through April and December (with the exception of Beer Sheva between 13 and 14, 23%)

The observation that the summer months are characterized by the lowest coefficient of variation is to be expected due to the relatively high stability of the local climate during this time interval, viz., there is very little variation in climatic conditions from one day to another. Similarly, the high coefficient of variation group is due to the relative instability of the local climate during those months.

5. Conclusions

An inter-comparison of the solar UVB, UVA and global radiation at two sites, Neve Zohar and Beer Sheva, based upon monthly average daily radiation intensity, clearness and UV indices was presented. The results of this study can be summarized as follows:

1. The global radiation at both sites is very similar with regard to monthly average daily intensity, clearness index, coefficient of variation and dispersion of individual daily values around the mean values.
2. The UVB radiation intensity is significantly greater for Beer Sheva relative to Neve Zohar throughout the year. This is in accordance with radiation scatter theory, viz., the radiation attenuation is inversely proportional to the wavelength raised to a power, λ^{-n}. This is also emphasized by the corresponding K_{TUVB} values, viz., they are two orders of magnitude less

than the corresponding values for global and UVA radiation. The UVB radiation exhibits the largest coefficient of variation for the monthly average daily values relative to the corresponding global and UVA radiation values. This indicates that there is a greater variation in daily UVB radiation intensities during a particular month relative to global and UVA radiation.

3. The UVA radiation and the K_{TUVA} values for Beer Sheva are higher than those for Neve Zohar throughout the year but to a much lesser degree than that for the UVB radiation. The observation that the relative attenuation of the UVA lies in between that for global and UVB radiation, albeit much closer to the global, is in agreement with radiation scattering theory. The behavior of the UVA radiation intensities at the two sites is shown to be very similar to that for the global radiation as indicated by the similarity of the regression equation developed to correlate the radiation data. This reflects the minimal effect that the scattering phenomena have within these two spectral ranges.
4. The monthly average hourly UVI values for Neve Zohar (Dead Sea) and Beer Sheva have been calculated and analyzed with emphasis on the midday hour values. It is apparent from the results that exposure to solar radiation at the Dead Sea is relatively safer than that in Beer Sheva throughout the year. In fact, due to the wavelength selective attenuation by the scattering phenomena, the UVI values at the Dead Sea will be lower, in general, than any other terrestrial site under similar global radiation intensities. This is a result of its location at the lowest terrestrial point on the earth. These findings are especially relevant with regard to the Dead Sea region, since it both an internationally recognized photoclimatherapy center and a popular resort area.

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References

[1] Fröhlich C, Wehrli C. Spectral distribution of solar irradiance from 25000 nm to 250 nm. In: Iqbal M, editor. An introduction to solar radiation. New York: Academic Press; 1981, p. 380–1 Appendix C.
[2] Stanhill G. Measurements of global solar radiation in Israel. Israel Journal of Earth Sciences 1970;19:91–6.
[3] Stanhill G. The radiation climate of the Dead Sea. Journal of Climatology 1987;7:247–56.
[4] Stanhill G, Ianetz A. Long-term trends in, and the spatial variation of, global irradiance in Israel. Tellus 1997;49B:112–22.
[5] Kudish AI, Evseev EG, Kushelevsky AP. The analysis of ultraviolet radiation in the Dead Sea Basin. International Journal of Climatology 1997;17:1697–704.
[6] Kudish AI, Evseev EG. Statistical relationships between solar UVB and UVA radiation and global radiation measurements at two sites in Israel. International Journal of Climatology 2000;20:1697–704.
[7] Dostrovsky A, Sagher F. The therapeutic effect of the Dead Sea on some skin diseases. Harefuah 1959;57:143–5.
[8] Avrach WW, Niordson AM. Treatment of psoriasis at the Dead Sea. Ugeskr Laeg 1974;13:2687–90.
[9] Abels DJ, Kattan BJ. Psoriasis treatment at the Dead Sea. Journal American Academy Dermatology 1985;12:639–43.

[10] Sukenik S. Spa treatment for arthritis at the Dead Sea area. Israel Journal Medical Science 1994;30:919–21.
[11] Moon P. Proposed standard solar radiation curves for engineering use. Journal Franklin Institue 1940;230: 583–617.
[12] Thekaekara, M.P., Data on incident solar energy. Supplement to the Proceedings of the 20th Annual Meeting of the Institute of Environmental Science 1974;21.
[13] Bener P. Final technical report no. DAJA 37-68-C-1017 (Europ. Res. Office, US Army); 1972.
[14] Reiter R, Munzert K, Sladkovic R. Results of 5-year concurrent recordings of global, diffuse and UV-radiation at three levels (700, 1800 and 2999 m a.s.l.) in the Northern Alps. Arch. Met. Geophy. Biokl. 182(Ser. B.30): 1–28.
[15] Blumthaler M, Ambach W, Rehwald W. Solar UV-A and UV-B radiation fluxes at two Alpine stations at different altitudes. Theoretical Applied Climatology 1992;46:39–44.
[16] Piazena H. The effect of altitude upon the solar UV-B and UV-A irradiance in the tropical Chilean Andes. Solar Energy 1996;57:133–40.
[17] Martínez-Lozano JA, Casanovas AJ, Utrillas MP. Comparison of global ultraviolet (290–385 nm) and global irradiation measured during the warm season in Valencia, Spain. International Journal of Climatology 1994;14:93–102.
[18] Martínez-Lozano JA, Tena F, Utrillas MP. Ratio of UV to global broad band irradiation in Valencia, Spain. International Journal of Climatology 1999;19:903–11.
[19] ACS. Cancer facts and figures, Publication 95-375. Atlanta, GA: American Cancer Society; 1995.
[20] Felipe P, Emerit I, Youssefi AA, Levy A, Cernjavski L, Freitas J, et al. Oxyradical-mediated clastogenic plasma factors in psoriasis: increase in clastogenic activity after PUVA. Photochemistry and Photobiology 1997;66: 497–501.
[21] McKinlay A, Diffey B. A reference action spectrum for ultraviolet induce erythema, in human skin. In: Passchler WR, Bosnajokovic BFM, editors. Human exposure to ultraviolet radiation: risks and regulations. Amsterdam: Elsevier Science Publishers B.V; 1987, p. 83–7.
[22] Martínez-Lozano JA, Tena F, Marín MJ, Utrillas MP, Lorente J, de Carbo X, et al. Experimental values of the UV Index during 2000 at two locations in Mediterranean Spain. International Journal of Climatology 2002;22:501–8.
[23] Martínez-Lozano JA, Marín MJ, Tena F, Utrillas MP, Sánchez-Muniosgruren L, González-Frías C, et al. UV index experimental values during the years 2000 and 2001 from the Spanish broadband UV-B radiometric network at two locations in Mediterranean Spain. Photochemistry and Photobiology 2002;76:181–7.
[24] Kudish AI, Abels D, Harari M. Ultraviolet radiation properties as applied to photoclimatherapy at the Dead Sea. International Journal of Dermatology 2003;42:359–65.
[25] Kudish AI, Lyubansky V, Evseev EG, Ianetz A. Statistical analysis and inter-comparison of the solar UVB, UVA and global radiation for Beer Sheva and Neve Zohar (Dead Sea), Israel. Submitted for publication.
[26] Kudish AI. Unpublished results.
[27] Ianetz A, Lyubansky V, Setter I, Evseev EG, Kudish AI. A method for characterization and inter-comparison of sites with regard to solar energy utilization by statistical analysis of their solar radiation data as performed for three sites in the Negev region of Israel. Solar Energy 2000;69:283–93.