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THE ANALYSIS OF ULTRAVIOLET RADIAT1ON IN THE DEAD SEA BASIN, ISRAEL

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ABSTRACT

The Dead Sea basin offers a unique site to study the attenuation of the ultraviolet (UV) radiation, as it is situated at the lowest point on Earth, about 400 m below sea level, and the air above the Dead Sea is characterized by a relatively high aerosol content due to the very high salt content of the Dead Sea. In view of its being an internationally recognized centre for climatotherapy, it is of interest to study both its UV intensity and attenuation as a function of wavelength relative to other sites. In order to provide a basis for intercomparison of the radiation intensity parameters measured at the Dead Sea, a second set of identical parameters were being measured simultaneously at a second site, located at a distance of *ca*. 65 km and to the west and situated above sea-level (Beer Sheva at +315 m a.s.l.). The ultraviolet radiation, both UV-B and UV-A, were monitored continuously at both sites using Solar Light Co. Inc. broad-band meters. In addition, sporadic measurements utilizing a narrow-band spectroradiometer were performed to ascertain the extent of site-specific spectral selectivity in the ultraviolet spectrum. The monthly average daily attenuation rates were found to vary from $-10{\cdot}2$ to $-17{\cdot}3$ per cent $1000\,m^{-1}$ and $-3{\cdot}3$ to $-8{\cdot}7$ per cent $1000\,m^{-1}$ for UV-B and UV-A, respectively. The average monthly values for UV-B and UV-A are $-14{\cdot}6$ per cent $1000\,m^{-1}$ and $-5{\cdot}4$ per cent $1000\,m^{-1}$, respectively. These values are in the range of values reported previously for studies performed at high altitudes, e.g. in the Alps and the Andes. The relative attenuation in the ultraviolet range as a function of wavelength, i.e. site-specific spectral selectivity, decreases with increasing wavelength. Consequently, the spectral range most effective with regard to erythema undergoes the highest degree of attenuation. These findings are in accordance with radiation scatter theory © 1997 Royal Meteorological Society. *Int. J. Climatol*., 17, 1697–1704

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KEY WORDS: Dead Sea; Beer Sheva, Israel; relative attenuation; ultraviolet UV-A and UV-B radiation; broad- and narrow-band measurements

INTRODUCTION

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 litre) and is situated at the lowest point on Earth, about 400 m below sea level. The Dead Sea basin is well known world-wide as a climatotherapy centre for the treatment of psoriasis and other skin diseases (Dostrovsky and Sagher, 1959; Avrach and Niordson, 1974; Abels and Kattan, 1985; Even-Paz *et al*., 1996). Over the past 30 years, tens of thousands of psoriatic patients from all over the world, although mainly from western Europe, have been treated at the Dead Sea spas. The success rate measured in terms of partial (i.e. marked improvement) to complete plaque clearance after 4 weeks of treatment, under strict medical supervision, exceeds 80 per cent (Abels and Kattan, 1985; Harari and Shani, in press). This high rate of success has been assumed to be associated with the unique ultraviolet radiation environment in the Dead Sea region.

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The attenuation of terrestrial solar radiation with optical path length (i.e. the distance the Sun's rays transverse through the Earth's atmosphere prior to being incident on the surface of the earth) is well documented. The terrestrial radiation is attenuated by two different phenomena, (i) atmospheric scattering by air molecules, water vapour and aerosols, and (ii) atmospheric absorption by ozone, water and carbon dioxide.

Scattering, which results in attenuation of the beam radiation by air molecules, water vapour and aerosols, has been the subject of numerous studies and approximate correlations have been developed to estimate the magnitude of the effect (Moon, 1940; Thekaekara, 1974). Air molecules are small compared with the wavelengths (λ) of radiation significant in the solar spectrum. 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 vapour in the air column above the observation site) and an empirical scattering coefficient for water vapour that varies approximately as λ^{-2} has been proposed. Moon (1940) developed an empirical scattering coefficient for aerosols, which varies approximately as $\lambda^{-0\cdot75}$. In all cases, the degree of attenuation by scattering is an inverse function of wavelength.

Absorption of solar radiation in the atmosphere is due mainly to ozone in the ultraviolet range and water vapour, 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) UV-C, with a spectral range from 100 to 280 nm, which is completely absorbed by the stratospheric ozone layer, (ii) UV-B, with a spectral range from 280 to 320 nm, which is mostly absorbed by the stratospheric ozone layer and virtually no solar radiation below 295 nm is incident on the Earth's surface, (iii) UV-A, with a spectral range from 320 to 380 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.

The potential increase of exposure to UV-B radiation is a cause of mounting concern regarding the thickness of the stratospheric ozone layer, because its intensity is the most sensitive to changes in the ozone layer thickness. It is this UV-B radiation that is considered to be the most biologically effective in producing sunburn of human skin and perhaps skin cancer. It is generally assumed that an increase in the UV-B intensity incident on the Earth's surface would be detrimental to the well-being of animal and plant life. For humans the problems of increased sunburn, skin cancer and eye diseases are usually emphasized, and the general destruction of plant tissue and living cells is also being investigated. These harmful effects of UV-B are, in fact, partially compensated for by some beneficial factors, which include its germicidal action, the production of vitamin-D and the treatment of various skin diseases such as psoriasis, rickets and dermatitis.

The attenuation of ultraviolet radiation with altitude (i.e. optical path-length) has been studied previously but only for sites above sea-level. Bener (1972) calculated the rate of increase for UV-B and UV-A intensities with increasing altitude (i.e. reduced attenuation with increasing altitude) between sea level and 5000 m. He found the rate of increase in UV-B intensity to vary between 2 and 16 per cent 1000 m^{-1}, whereas that for UV-A varied up to 16 per cent 1000 m^{-1}. The rate is also a function of solar elevation; the latter is a function of site latitude, time of year and time of day.

Reiter *et al*. (1982) measured the daily sums of UV radiation in the spectral range from 310–340 nm in the Northern Alps at altitudes of 700, 1800 and 3000 m above m.s.l. (mean sea level). They determined an increase in cumulative daily radiation intensities with increasing site altitude of about 14–27 per cent 1000 m^{-1} from 5 years of recorded measurements. Blumthaler *et al*. (1985) observed an average rate of increase of 9 per cent 1000 m^{-1} for global radiation and 23·7 per cent 1000 m^{-1} for the cumulative daily erythema effective component of the solar radiation for two Alpine sites. In addition, Blumthaler *et al* (1992) determined the average annual rate of increase for the erythema effective component to be 19 per cent 1000 m^{-1} and that for UV-A to be 11 per cent 1000 m^{-1} in the Alps.

Piazena (1996) has reported recently the effect of altitude upon the UV-B and UV-A radiation intensities in the tropical Chilean Andes. He measured, using two Grasnick filter photometers, the UV radiation in the spectral range between 308 and 319 nm (UV-B) and between 313 and 374 nm (mainly UV-A) between sea level and 5500 m a.s.l. He observed, for solar elevations between 20° and 90°, that the increase in UV-B radiation was about 8–10 per cent 1000 m^{-1} and for UV-A it varied from 15 to 7 per cent 1000 m^{-1} with increasing solar elevation.

The Dead Sea basin offers a unique site to study the attenuation of the UV radiation because it is situated at the lowest point on earth, about 400 m below sea level, and the air above the Dead Sea is characterized by a relatively high aerosol content due to the very high salt content of the Dead Sea. In view of its being an internationally recognized centre for climatotherapy, it is of interest to study both its UV intensity and attenuation as a function of wavelength relative to other sites. In order to provide a basis for intercomparison of the radiation intensity parameters measured at the Dead Sea, a second set of identical parameters were measured simultaneously at a second site, located at a distance of *ca*. 65 km to the west and situated above sea level (Beer Sheva at +315 m a.s.l.). In the following, we analyze the results of the first 2 years of an ongoing research programme.

MEASUREMENTS

The radiation data on which this study is based are being monitored at two meteorological stations: one located on the western shore of the Dead Sea, at a site called Neve Zohar; the second is located in Beer Sheva, on the campus of the Ben-Gurion University of the Negev. The site parameters for the two stations are listed in Table I. 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 UV-B and a Solar Light Co. Inc., analogue UV-A version of Model 501A UV-Biometer for the measurement of UV-A. 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-minute intervals (i.e. the meters are scanned at 10 s intervals and average values at 10 minute intervals are calculated and stored). The Beer Sheva meteorological station is located on the roof of the building housing the Department of Chemical Engineering and its Solar Energy Laboratory and the data logger is downloaded directly to a desk-top computer. The Neve Zohar station is located on the roof of the building housing the Tamar Regional Council and the data is transmitted periodically from the data logger to Beer Sheva via a modem. The UV-B and UV-A measurements were initiated at Neve Zohar in February 1995 and the radiation was monitored continuously except for interruptions; those scheduled to enable factory calibration checks and random ones caused by power failures. The UV-B measurements were inaugurated at the Beer Sheva site in May 1994 and those for UV-A in June 1995 and were monitored continuously except for the above-mentioned interruptions. Both of these meteorological stations are part of the national network of meteorological stations and are connected by modem to the Israel Meteorological Service, located at Beit Dagan.

The selection of this particular type of UV meter (biometers) was dictated in part by one of the goals of this research programme, namely, to develop a data base for monthly average daily and hourly UV-B and UV-A values for the Dead Sea region. Such a data base will enable physicians at the Dead Sea therapeutic spas to establish a consistent treatment protocol for solar phototherapy and thereby ensure that the patients receive the proper dosage of UV radiation. Thus, it was decided to utilize biometers that measure the biologically effectiveness of the UV-B 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 UV-B spectral range and the erythema action spectra (McKinlay and Differ, 1987). Consequently, the UV-B 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 $\sim 0{\cdot}01$ at 320 nm and $\sim 0{\cdot}001$ 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 $= 0{\cdot}0583$ W m^{-2} for an MED of 21 mJ cm^{-2}. The UV-A meter measures the irradiating flux in the UV-A spectral range in units of W m^{-2}.

Table I. Site parameters for the two meteorological stations

	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

The Solar Light Co. Inc. meters, both for UV-B and UV-A, installed at both sites are classified as broad-band meters. They measure the cumulative radiation flux over their respective spectral ranges and consequently are incapable of providing any information regarding site-specific spectral selectivity. In order to overcome this deficiency we have also made sporadic measurements utilizing a narrow-band spectroradiometer, UV-Optronics 742, to scan from 295 to 380 nm at 1 nm intervals (the instrument's bandpass is 1·5 nm, as per the manufacturers' specifications). Such measurements could not be performed concurrently at the Dead Sea and Beer Sheva, because we have only a single spectroradiometer in our possession. In order to overcome this obstacle, we have utilized the broad-band meters at both sites to ascertain that the overall radiation flux densities are similar prior to performing an intercomparison between spectroradiometer measurements performed on two different days. In addition, the horizontal global radiation intensity values measured at both sites were compared. The latter, as will be elaborated upon in the discussion section, provide a better criterion for the justification of the intercomparison of the narrow-band spectra, because they are least affected by the additional optical path-length. The global radiation intensities are measured by Kipp and Zonen, Model CM11 and Eppley, Model PSP pyranometers at Neve Zohar and Beer Sheva, respectively.

The spectroradiometer measurements, utilizing the UV-Optronics 742, were performed sporadically, as mentioned previously. The spectroradiometer and its peripheral equipment were transported to the Neve Zohar site about once every two to three weeks for a day of measurements. The latter consist of a single scan through the ultraviolet range (i.e. 295 to 380 nm) once an hour from about 0930 until 1530 (Israel Standard Time). An identical set of measurements were performed at the Beer Sheva site on a number of days, both before and after the measurement day at Neve Zohar, in order to enhance the probability of obtaining two very similar days for the purpose of intercomparison.

The UV-Optronics 742 is a portable spectroradiometer well suited for both field and laboratory measurements over the 200 to 800 nm wavelength region. The ultra-low stray light level, essential for accurate UV solar spectral measurements, is achieved by using a double monochromator with dual holographic gratings in combination with a specially selected cosine receptor. A teflon dome diffuser is used in the 250 to 400 nm wavelength range. It is periodically calibrated in the laboratory against a standard lamp (Quartz halogen 200 W, Optronics Laboratories Model 220 A) traced to the NIST.

The UV meters are returned once a year to Solar Light Co. Inc. for factory callibration checks using secondary standards. The Israel Meteorological Service performs periodic calibration checks on the global radiation pyranometers in the field using a secondary standard and maintains both stations.

RESULTS

We present in this section the results of our data analysis with respect to the attenuation of the ultraviolet radiation incident at the Dead Sea basin relative to that at Beer Sheva. Any discussion of the monthly average daily and hourly ultraviolet radiation values must be postponed until the radiation data bases for the two sites are sufficiently broad to allow such an analysis.

In Table II are listed the monthly average daily UV-B and UV-A radiation values for both sites together with corresponding number of days available for each month. Only those days for which a complete set of data exist for both sites are included in the analysis. The monthly average daily percentage relative difference between the ultraviolet radiation intensities, both UV-B and UV-A, measured concurrently at Neve Zohar and Beer Sheva are plotted in Figure 1. The percentage relative difference has been defined for this analysis in the following manner:

$$\text{percentage relative difference } = (\text{UV-i}_{\text{Neve Zohar}} - \text{UV-i}_{\text{Beer Sheva}}) \times 100/\text{UV} - \text{i}_{\text{Beer Sheva}}$$

The results of the spectroradiometer analysis are summarized in Figures 2 and 3 for the UV-B and UV-A spectral ranges, respectively. These measurements were performed to determine if there is any site-specific spectral selectivity at Neve Zohar relative to Beer Sheva. The results shown for August 5 and 6 (for measurements performed at Beer Sheva and Neve Zhohar, respectively) are typical of those calculated for the intercomparison of these two sites. The data are presented as the daily average of the corresponding hourly ratios of the individual measured radiation intensities at 1 nm intervals for Neve Zhohar relative to Beer Sheva.

Table II. Monthly average daily UV-B and UV-A radiation at Neve Zohar and Beer Sheva

	UV-B (MED/H)			UV-A (W m^{-2})		
Month	Neve Zohar	Days	Beer Sheva	Neve Zohar	Days	Beer Sheva
January	5·36	62	5·76	139·60	62	142·86
February	7·44	47	8·29	166·35	39	175·19
March	12·19	84	13·18	237·84	55	238·77
April	16·33	89	17·99	305·41	60	300·62
May	20·54	93	23·33	357·57	62	370·37
June	23·28	90	26·25	386·68	71	400·05
July	21·45	62	23·95	365·54	62	375·08
August	19·89	62	22·26	347·28	62	358·08
September	15·79	60	17·81	291·56	60	302·41
October	10·58	62	12·12	220·25	62	234·24
November	7·03	40	7·69	162·78	60	169·54
December	4·78	37	5·31	132·27	55	137·68

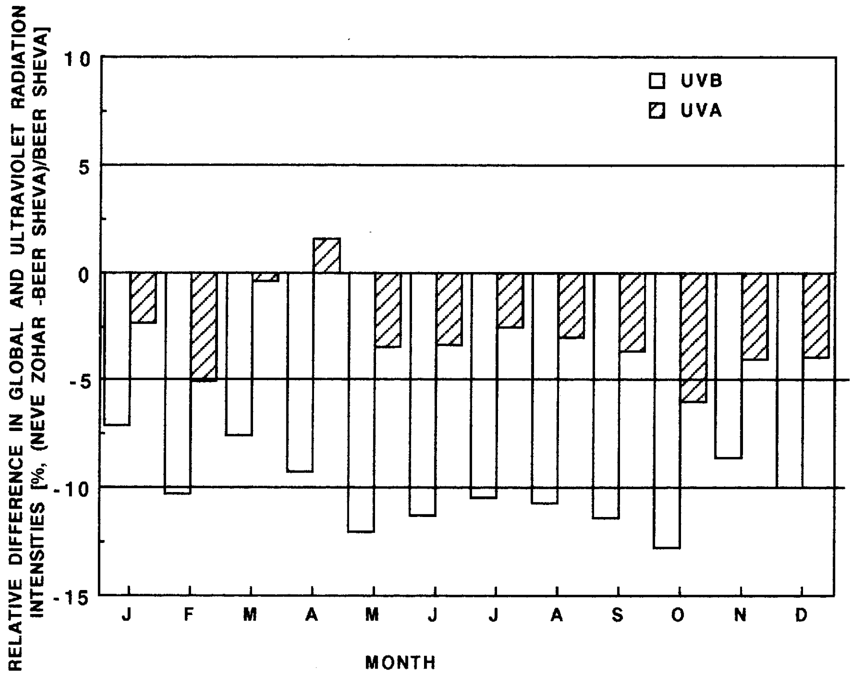

Figure 1. The monthly average daily percentage relative difference between the UV-B and UV-A radiation intensities measured concurrently at Neve Zohar and Beer Sheva

DISCUSSION

The narrowness of the presently available individual monthly data bases is apparent from Table I; in the case of both UV-B and UV-A, three months have individual data bases consisting of less than 60 days (February, November and December for UV-B and February, March and December for UV-A). Consequently, as mentioned previously, it is too premature for any discussion of the monthly average daily and hourly ultraviolet radiation values incident at either site. Nevertheless, there is sufficient data to analyse the extent of additional attenuation in the UV-B and UV-A radiation intensities caused by the extended optical path-length through the unique microclimate at the Dead Sea basin relative to Beer Sheva.

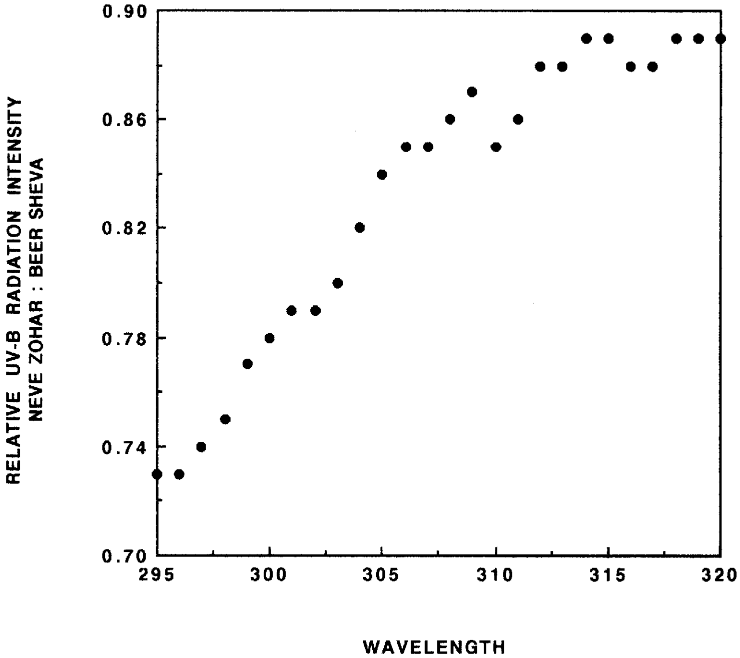

Figure 2. The average daily ratio of the UV-B radiation intensities measured on two different but similar days at Neve Zohar and Beer Sheva as a function of wavelength (from 295 to 320 nm)

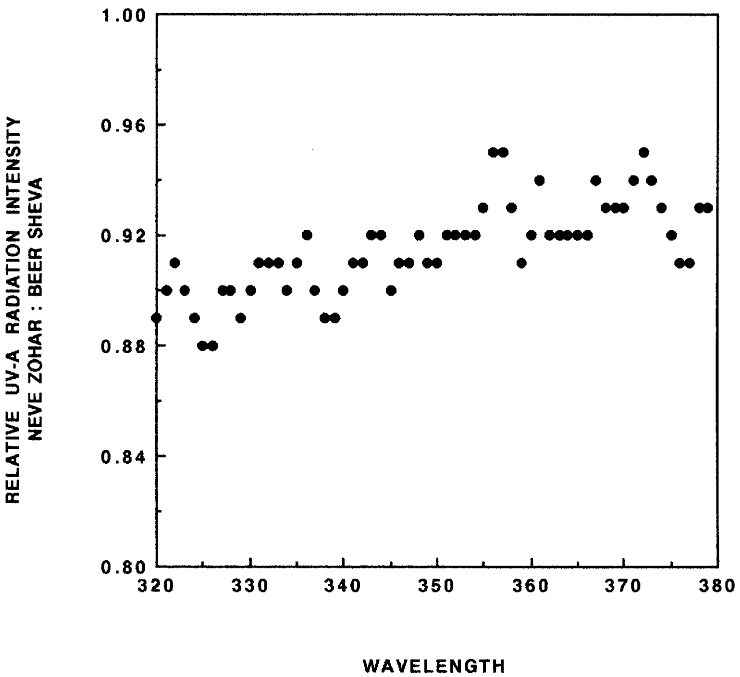

Figure 3. The average daily ratio of the UV-A radiation intensities measured on two different but similar days at Neve Zohar and Beer Sheva as a function of wavelength (from 320 to 380 nm)

The attenuation in the ultraviolet radiation, both UV-B and UV-A, incident at the Dead Sea basin relative to that at Beer Sheva is shown in Figure 1 as the monthly average daily relative attenuation. In the case of UV-B the minimum attenuation is $-7{\cdot}0$ per cent in January and the maximum is $-12{\cdot}0$ per cent in May; whereas in the case of UV-A the corresponding values are $+1{\cdot}6$ per cent in April (i.e. essentially equivalent; within instrument error) and $-6{\cdot}0$ per cent in October. The anomalous relative attenuation values in the case of UV-A (Figure 1) observed for the months of March and April may be a consequence of the difference in local climatic conditions experienced at both sites during these months. These two months are characterized by significant fluctuations in the weather pattern typical of the relatively rapid transition from winter to summer climates. We believe that it may be justified to neglect the UV-A data for March and April until the data base is broadened and other factors, such as aerosol optical thickness, become available for analysis. Neglecting the UV-A data for March and April, the minimum relative attenuation is then $-2{\cdot}3$ per cent in January. Consequently, the average monthly relative attenuation for UV-B is $-10{\cdot}1$ per cent and that for UV-A is $-3{\cdot}7$ per cent. These relative attenuation rates, prorated on the basis of 1000 m, are then equivalent to the following

(i) UV-B:
  (a) monthly average daily relative attenuation rate range $-10{\cdot}2$ to $-17{\cdot}3$ per cent 1000 m^{-1};
  (b) average monthly relative attenuation rate $-14{\cdot}6$ per cent 1000 m^{-1}.
(ii) UV-A:
  (a) monthly average daily relative attenuation rate range $-3{\cdot}3$ to $-8{\cdot}7$ per cent 1000 m^{-1};
  (b) average monthly relative attenuation rate $-5{\cdot}4$ per cent 1000 m^{-1}.

These attenuation rates are within the range of values reported previously in the literature for both the Alps and the Andes (as described in the introduction). In addition, they are in accordance with radiation scattering theory. The degree of attenuation is an inverse function of wavelength and, therefore, the rate of attenuation of the UV-B radiation is greater than that for the UV-A radiation. In fact, the average monthly relative attenuation rate for UV-B is more than twice that for UV-A.

The spectroradiometer measurements were performed in order to determine to what extent specific spectral selectivity exists between the two sites. As mentioned above, owing to practical limitations the spectroradiometer measurements were performed at the two sites on different days. The global radiation monitored continuously at both sites was used as the primary criterion for the intercomparison of the hourly spectroradiometer scans. Only those scans for which the corresponding hourly global radiation intensities were within ± 5 per cent of each other (essentially within the accuracy of the pyranometers) were considered in the analysis. The hourly UV-B and UV-A radiation intensities monitored continuously by the broad-band meters (Solar Light Co. Inc.) were utilized as secondary criteria. The preference of the global radiation intensity criterion is in accordance with radiation scatter theory; i.e. the attenuation of global radiation by scattering is significantly lower than that for ultraviolet radiation due to the monotonic increase in wavelength (cf. why is the sky blue?).

A single but typical set of results for the intercomparison of the spectroradiometer measurements is shown in Figures 2 and 3 for the UV-B and UV-A spectral ranges, respectively. Once again, we observe that the degree of relative attenuation decreases with increasing wavelength as expected from radiation scatter theory. The degree of relative attenuation in the UV-B spectral range decreases, i.e. the relative radiation intensities increase from approximately 0·73 to 0·89, as the UV-B spectrum is scanned from 295 to 320 nm. In the case of UV-A the degree of attenuation is smaller and decreases at a much lower rate, i.e. the relative radiation intensities increase from approximately 0·88 to 0·96, as the UV-A spectrum is scanned from 320 to 380 nm. In the case of UV-B radiation intensities it is important to note that the spectral range most effective with regard to erythema undergoes the highest degree of attenuation.

The attenuation of the ultraviolet radiation intensity levels at the Dead Sea relative to Beer Sheva has been attributed to scattering and not absorption, because absorption bands to not exist in the ultraviolet range. In addition, it is reasonable to attribute the scattering primarily to air molecules and aerosols and not to water vapour, because the Dead Sea basin is characterized as having a very dry climate. We plan to expand our experimental measurements, in the future, to include aerosol optical thickness and total water vapour. This will enable us to attribute the relative attenuation on a quantitative basis.

CONCLUSIONS

The attenuation of both UV-B and UV-A radiation intensities incident at the Dead Sea basin relative to that at Beer Sheva have been studied in detail. The monthly average daily attenuation rates vary from $-10{\cdot}2$ to $-17{\cdot}3$ per cent 1000 m^{-1} and $-3{\cdot}3$ to $-8{\cdot}7$ per cent 1000 m^{-1} for UV-B and UV-A, respectively. The average monthly attenuation rates for UV-B and UV-A are $-14{\cdot}6$ per cent 1000 m^{-1} and $-5{\cdot}4$ per cent 1000 m^{-1}, respectively. These values are in the range of values reported previously for studies performed at high altitudes, e.g. in the Alps and the Andes. The relative attenuation in the ultraviolet range as a function of wavelength, i.e. site-specific spectral selectivity, decreases with increasing wavelength. Consequently, the spectral range most effective with regard to the erythema undergoes the highest degree of attenuation. These findings are in accordance with radiation scatter theory.

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