ATMOSPHERIC SUN PROTECTION FACTOR ON CLEAR DAYS: ITS OBSERVED DEPENDENCE ON SOLAR ZENITH ANGLE AND ITS RELEVANCE TO THE SHADOW RULE FOR SUN PROTECTION

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Abstract—Global irradiances measured in seven 5-nm bands of UV-B at Rockville, MD (39.1°N, 77.1°W) on 28 clear days near the summer solstice are convoluted with the erythemal action spectrum of human skin to determine dose rates at various hours of the day. These rates are averaged with respect to solar zenith angle to obtain the diurnal variation of mean dose rate and of the Sun Protection Factor (SPF) of the atmosphere (reciprocal of the normalized atmospheric transmissivity) on a typical clear summer day in Rockville. At a 45° zenith angle the atmospheric SPF is computed to be 2.7 and increases rapidly to greater than 7 at 60°.

Dose rates are integrated with respect to time to obtain estimates of mean doses for various periods during clear days at Rockville in mid summer and near the autumnal equinox. In mid summer the effective erythemal UV-B exposure during the period when the solar zenith angle is less than 45° is about five times greater than that during the remainder of the day. These observations provide scientific basis for a shadow rule for solar UV-B protection: when shadows are shorter than objects casting them, sunburn is much more likely than at other times.

INTRODUCTION

The intensity of solar ultraviolet radiation reaching the surface of the earth depends on the sun's UV at the top of the atmosphere, the amount of absorbers, reflectors and scatterers in the atmosphere and on the solar zenith angle. To estimate the time and space distributions of biological effects by radiation in the UV-B band (290–325 nm)† it is necessary to determine the relationships between the irradiance of the effective UV received at the surface of the earth and such factors as the solar zenith angle and the total thickness of atmospheric ozone. This study focuses on the diurnal variation of UV radiation that causes erythema (reddening) of human skin. This type of skin trauma (sunburn) is thought to be related to more serious diseases such as skin aging and skin cancer. The relationships between UV-B dose rates and ozone thickness and cloudiness will be examined in a subsequent paper.

The relative biological effects of UV radiation of different wavelengths varies according to a so-called action spectrum. The convolution of the action spectrum for erythema of human skin and the solar irradiance gives an effective dose rate of the UV radiation for causing sunburn. This dose rate can then be related to the corresponding solar zenith angle or the time of day on a given date and location. Furthermore, the dose rates can be integrated over time to give total doses during specific periods.

Several researchers have computed effective UV dose rates using theoretical models of atmospheric transmissivity of UV radiation and have used these results to compute doses for different latitudes and at various times of day and year (Henriksen *et al.*, 1990; Dahlback *et al.*, 1989). Scotto *et al.* (1988) used 12 years (1974–85) of UV-B observations at eight US cities obtained by Robertson–Berger meters which have sensors weighted only very approximately by the erythemal action spectrum for human skin. UV-B doses were computed from these data for periods ranging from a half hour to months and years at all stations.

Recently the Solar Radiation Laboratory of the Smithsonian Environmental Research Center (SERC) at Edgewater, MD (1989) published 13 years (1975 to 1988) of preliminary UV-B irradiance observations at 1 h time resolution in eight 5-nm bands measured at Rockville, MD (available on 13 IBM PC compatible floppy disks). These data offer an excellent opportunity to compute UV-B dose rates from observations for any hour throughout the year.

MATERIALS AND METHODS

SERC observed global (direct and diffuse) UV-B irradiance on a horizontal surface in eight 5-nm bands centered approximately on wavelengths 290, 295, 300, 305, 310, 315, 320 and 325 nm at Rockville (39.1°N, 77.1°W). The observations were collected with high precision scanning radiometers (Goldberg, 1982, 1986). The data rec-

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†*Abbreviations*: CIE, Commission Internationale de l'Eclairage; EST, Eastern Standard Time; MED, minimum erythemal dose; SERC, Smithsonian Environmental Research Center; SPF, sun protection factor; UV-B, ultraviolet, band B.

Table 1. Illustration of a discrete-valued numerical integration of the convolution of UV-B irradiance and the CIE relative erythemal action spectra from observations on June 9, 1984 during 1 h from 12 to 1 p.m. EST at Rockville, MD

Nominal wavelength	UV-B ([W/m²] /5 nm)	Erythemal action	Product
295 nm	0.009	1.000	0.009
300	0.074	0.650	0.048
305	0.375	0.220	0.083
310	0.830	0.075	0.062
315	1.440	0.025	0.036
320	1.960	0.009	0.018
325	2.320	0.003	0.007

Sum = erythemally effective UV-B dose rate = 0.263 W/m²

Table 2. Erythemal UV-B dose rates from the sun at the zenith and at a 45° zenith angle and the SPF at 45° on each of the 28 clear summer days in this study

Year	Date	Zenith dose rate	45° dose rate	45° SPF†
1984	May 25	0.271 W/m²	0.104 W/m²	2.6
	June 4*	0.297	0.106	2.8
	June 9*	0.297	0.105	2.8
	June 26*	0.207	0.080	2.6
	July 8*	0.221	0.085	2.6
	Aug. 21	0.264	0.104	2.5
1985	May 4	0.222	0.084	2.6
	May 8	0.210	0.084	2.5
	May 14	0.264	0.092	2.9
	May 26	0.236	0.086	2.8
	June 1*	0.294	0.106	2.8
	June 25*	0.263	0.096	2.7
	July 7*	0.245	0.093	2.6
1986	May 2	0.197	0.077	2.6
	May 3	0.188	0.067	2.8
	May 4	0.186	0.070	2.7
	May 5	0.206	0.072	2.9
	May 29	0.251	0.086	2.9
	May 31*	0.219	0.083	2.6
	June 3*	0.233	0.083	2.8
	June 18*	0.265	0.097	2.7
	June 21*	0.262	0.098	2.7
	July 4*	0.224	0.082	2.7
1988	May 7	0.211	0.067	3.2
	May 26	0.198	0.074	2.7
	May 29	0.196	0.067	2.9
	June 5*	0.198	0.077	2.6
	July 2*	0.211	0.081	2.6
1984–1988 means		0.233	0.086	2.7
Standard errors		0.006	0.002	0.03

*Mid-summer days.
†SPF at 45° is the zenith dose rate divided by the dose rate at a 45° solar zenith angle, rounded to 2 significant digits.

orded on the SERC floppy disks are averages over 1 h periods beginning on the hour EST (Eastern Standard or 75°W Meridian Time) from sunrise to sunset in units of joules/(m² nm min). This study uses seven bands of these data at nominal wavelengths from 295 to 325 nm for clear summer and autumn days in 1984 through 1988.

The convolution of the erythemal action spectrum and UV-B irradiances is performed by a discrete-valued numerical integration illustrated in Table 1. The Commission Internationale de l'Eclairage (CIE) relative action spectrum for erythema of human skin is used in this study (McKinlay and Diffey, 1987). This spectrum is defined by analytic formulas and thus can be evaluated at any desired wavelength. The values used here are computed for nominal wavelengths that are evenly spaced every 5 nm. The observed SERC irradiances are recorded at unevenly-spaced wavelengths that are the means of the half-power points of the individual band filters. These UV-B data must, therefore, be interpolated to the nearby nominal wavelengths before the convolution is performed. Because of the great variation with wavelength of UV-B irradiance at the earth's surface, this interpolation is done logarithmically.

The individual products in each discrete-valued convolution are then summed to obtain an estimate of the total erythemally effective UV-B dose rate for the time and date of the observation in W/m² on a horizontal surface expressed as equivalent effective irradiance at 297 nm, the wavelength at which the erythemal sensitivity is at a maximum. At the small solar zenith angle (17°) used in the example in Table 1 these products peak at 305 nm and fall off by an order of magnitude at either end of the UV-B band. The peak shifts toward longer wavelengths as zenith angles increase. This convolution method has been used by others (Luther, 1985, Parrish et al., 1978). (See Discussion for comments on possible errors of this method.)

The analysis of the dose rates obtained by the above procedure is carried out in two steps. First, the mean variation of the UV-B dose rate as a function of the solar zenith angle is determined. Secondly, these dose rates are integrated with respect to time to obtain UV-B doses over chosen periods.

Because cloudiness greatly complicates the analysis of UV-B data, this study is confined to clear days. Perfectly cloud-free days in Rockville are rare, and compromises, therefore, had to be made in selecting clear days to be analyzed. Weather records (NOAA, 1984–1988) at Washington National Airport (about 25 km south of Rockville) provide daily sunshine and cloudiness data for the candidate days. Furthermore, the smoothness of the time variation of observed dose rates gives clues about the clarity

of the day. A total of only 47 days in 1984–1988 (28 in summer and 19 near the autumnal equinox) are considered satisfactory for this study. These days are listed in Tables 2 and 4. In this paper, "summer" is defined as the 3.5-month period centered on the June solstice (May–mid August).

The dose rates computed by the convolutions are interpolated to zenith angles at every 5 degrees from 0° to 60° for each of the 28 clear summer days. (Values near the zenith, of course, are extrapolations because the zenith distance of the sun is never less than 15.6° at Rockville). The interpolated dose rates for these 28 days are then averaged with respect to solar zenith angle to obtain the mean diurnal distribution of values for a typical clear summer day at Rockville. The means of these dose rates are listed in Table 3 opposite the corresponding zenith angle.

The solar zenith angles for the hourly SERC observations used in this study are 1 h averages computed from a solar ephemeris derived from the "low precision" (0.01°) formulas in the Astronomical Almanac (US Naval Observatory, 1990). The time of the observation is taken to be the middle of the 1 h UV-B collection interval.

For the purpose of integrating dose rates to obtain UV-B exposures for various periods of the day in the preparation of Fig. 2, the independent variable is time in hours before or after local noon rather than zenith angle because the latter is not a linear function of time, especially near local noon (time when sun is due south). Since it is preferable to use days during which the solar declination

Table 3. Mean erythemal UV-B dose rate, mean normalized transmissivity and SPF (Sun Protection Factor) of the atmosphere for solar zenith angles to 60° during the 28 clear summer days analyzed. (SPF is the reciprocal of the transmissivity at the corresponding solar zenith angle)

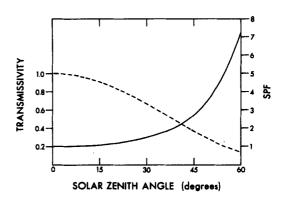| Zenith angle	Dose rate	Transmissivity	SPF
0°	0.233 W/m^2	1.00	1.0
5	0.231	0.99	1.0
10	0.224	0.96	1.0
15	0.212	0.91	1.1
20	0.197	0.85	1.2
25	0.178	0.76	1.3
30	0.156	0.67	1.5
35	0.133	0.57	1.8
40	0.109	0.47	2.1
45	0.086	0.37	2.7
50	0.065	0.28	3.6
55	0.046	0.20	5.0
60	0.032	0.14	7.1

Figure 1. Mean Sun Protection Factor (SPF) of the atmosphere (solid line, right scale) and the mean normalized transmissivity (dashed line, left scale) against solar zenith angle in degrees (bottom scale) for 28 clear summer days in 1984, 1985, 1986 and 1988 at Rockville, MD.

falls within narrow limits, only the 14 summer days occurring within 3 weeks of the summer solstice on June 21 are used in deriving Fig. 2(a). This period is hereafter called "mid summer" in this paper.

The bar graphs of mean dose rates in Fig. 2 are based on means of observations symmetric with respect to standard time noon. For example, the dose rate for hour 1.5 is the mean of all observations during both the 10 a.m.–11 a.m. and the 1 p.m.–2 p.m. periods. (The average dose rate bars fall exactly on the half hours because differences between local noon and standard time noon cancel out in the averaging of morning and afternoon observations.) The bar graphs in Fig. 2 are typical of the variation of dose rate against hour either before or after local noon for any location near the latitude of Rockville during the specified season.

The asymmetry of the times of the SERC observations

with respect to local noon provides greater zenith angle resolution for the derivation of the mean dose rates in Table 3, whereas the averaging of data about standard time noon in Fig. 2 sacrifices some of this time resolution for the sake of simplicity.

RESULTS

The mean summer erythemally effective UV-B dose rates at Rockville obtained by the above methods are then normalized by the estimated mean rate at the zenith (0.233 W/m^2) to obtain mean UV-B transmissivities relative to a datum of one for an overhead sun. The mean normalized transmissivities are shown in Fig. 1 and listed in Table 3 at 5° intervals of solar zenith angle. Table 3 also lists the zenith-angle-dependent mean dose rates and reciprocals of the mean normalized transmissivities, which I shall call the mean normalized sun protection factors (SPF) of the atmosphere relative to one for an overhead sun. The variation of SPF with zenith angle is also shown in Fig. 1.

This SPF, similar to the numerical rating of a sunscreen lotion, gives the relative protection from UV-B afforded by the atmosphere for various solar zenith angles. In other words, the value of the SPF specifies the magnitude of the attenuation factor for effective UV-B in relation to its overhead intensity.

The value of 2.7 in Table 3 for the mean normalized SPF at a zenith angle of 45 degrees is good justification for the rule of thumb for sun protection that the author proposed in a popular science article (Holloway, 1987) and in The Lancet (Holloway, 1990): "When your shadow is shorter than you are tall, the sun is much more likely to burn you than at other times." Shadows on a horizontal surface outdoors in the sun are shorter than the objects casting them when the solar zenith angle is less than 45 degrees. At those times the mean SPF at Rockville on clear summer days is smaller than 2.7. This mean SPF increases to greater than seven at a 60° zenith angle. On the solstice the solar zenith angle at Rockville is 15.6° at local noon, correspond-
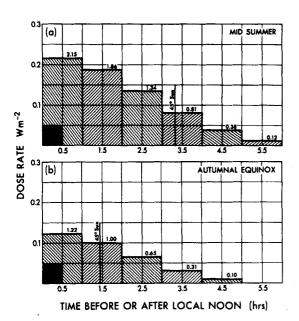
Table 4. Erythemal dose rates at a 45° solar zenith angle on each of the 19 clear days near the autumnal equinox and their mean

Year	Date	45° Dose rate
1984	Sept. 17	0.103 W/m^2
	Sept. 19	0.105
	Sept. 20	0.105
	Sept. 21	0.109
1985	Sept. 20	0.086
	Sept. 28	0.110
	Sept. 29	0.106
	Oct. 7	0.093
1986	Sept. 9	0.093
	Sept. 13	0.110
	Sept. 17	0.104
	Oct. 7	0.098
1987	Sept. 24	0.100
	Sept. 26	0.095
	Sept. 28	0.089
	Oct. 4	0.081
	Oct. 5	0.093
1988	Sept. 15	0.105
	Sept. 27	0.092
1984–1988 Mean		0.099
Standard error		0.002

Figure 2. Bar graphs of mean effective erythemal UV-B dose rate (in W/m² on left scale) against time in hours before or after local noon (bottom scale) at Rockville, MD for (a) 14 clear days within 3 weeks of the summer solstice and (b) 19 clear days near the autumnal equinox. The product of dose rate on the ordinate and time on the abscissa in seconds defines an area equivalent to a UV-B dose in J/m². The darkly shaded squares at the lower left-hand corners of the graphs equal a dose of 90 J/m², or about a quarter of a MED for individuals of skin Type II. Therefore, the mean dose in MED units for any period can be estimated by counting squares covered by the bars in these graphs and dividing by 4. The truncated lines at 3.31 and 1.45 h delineate the mean hour when the solar zenith angle is 45° during the two seasons. The figures above the bars are doses in MED units (360 J/m²) for the individual 1 h bars.

ing to a mean SPF of only 1.1. Therefore, the rate of effective erythemal UV-B exposure is significantly less at zenith angles greater than 45° than at midday in summer.

The shadow rule is generally more accurate than clock rules for predicting the sunburning potential of solar UV-B. Rules based on time of day, such as the warning to avoid the midday sun between 10 a.m. and 2 p.m., are poor delimiters of periods having the smallest zenith distances associated with highest UV-B dose rates because of seasonal changes, broad time zones, daylight saving time and the great variation of latitude and longitude among different locations.

The effective UV-B erythemal dose during any period on an average clear day in Rockville in summer can be estimated by a numerical time integration of observed dose rates obtained in this study. Figure 2(a) shows a bar graph of the mean dose rates of 14 mid summer days for each hour (before or after local noon) on the half hour up to 5.5 h. Beyond 6 h from noon the sun's elevation above the horizon is less than 15° and the dose rate

is considered to be negligible.

Since the ordinate of the graphs in Fig. 2 is dose rate in W/m² and the abscissa is time, any area on this diagram represents dose in J/m². For example, the darkly shaded square in the lower left-hand corner is 90 J/m². This figure is the product of 0.05 W/m² and 1800, the number of seconds in a half hour. The total dose in J/m² from local noon to sunset can be estimated as 90 times the number of squares covered by the bars. The total number of squares covered by the bars in Fig. 2(a) is 26.6. This implies an afternoon dose of about 2400 J/m² or a daily dose of 4800 J/m² on a typical mid summer clear day in Rockville.

For argument, arbitrarily assume that an average minimum erythemal dose (MED) for fair-skinned individuals is 360 J/m² based on the range of 20–50 mJ/cm² (200–500 J/m²) determined by Pathak et al. (1978) to cause a barely perceptible reddening in skin types I–III. Therefore, one square on Fig. 2 is one quarter MED by the above definition. Thus the 26.6 squares under the bars in Fig. 2(a) represents 6.7 MED for the mean mid summer afternoon dose. (The mean full-day dose is 13.4 MED.) A truncated vertical line is drawn on this graph at 3.31 h after local noon to delineate the mean mid summer time when the sun has a zenith angle of 45° at 39°N. The area under the bars to the right of this 45° line gives the mean UV-B dose accumulated in the afternoon from the 45° sun to sunset. This area is about 4.2 squares or equivalent to a little more than one MED as defined above.

Thus near the solstice at Rockville the UV-B dose accumulated between local noon and the time when the sun reaches a 45° zenith angle is 5.6 MED, which is more than five times the dose accumulated during the rest of the afternoon, a period of about 4 h. This shows that the shadow rule for sun protection is confirmed by both this dose rate integration and the diurnal SPF curve derived above for clear summer days in Rockville.

The relatively slow accumulation of UV-B exposure below a solar altitude of 45° at latitudes near that of Rockville is due to two factors; viz., the rapid increase in atmospheric path length with increasing solar zenith angle and the rapid approach of the sun to the horizon at these low solar altitudes.

The reader must be cautioned that the analysis above is based on average conditions of atmospheric transmission and solar path geometry at Rockville in summer. Estimated dose rates from an overhead sun vary from 0.186 to 0.297 W/m² among the 28 clear summer days in Table 2, and those at other zenith angles vary proportionally. The standard error of the 28-day mean overhead dose rate in Table 2 is 0.006 W/m².

Near the autumnal (September) equinox, however, at latitudes near Rockville's 39°, the sun does not rise much above 45° at local noon, but it spends much more time near this altitude of moderate SPF

than in mid summer. In order to examine this situation, 19 additional clear days are selected from dates near the autumnal equinox in the years 1984–1988. These dates are listed in Table 4 along with the corresponding observed dose rates at a 45° zenith angle.

Compare the mean dose rate of 0.099 W/m² at a 45° sun near the autumnal equinox in Table 4 with the summer mean for this same zenith angle, *viz.*, 0.086 W/m² in Tables 2 and 3. The higher value at the autumnal equinox may in part be due to the thinner ozone layer that is observed climatically in autumn in mid latitudes (London, 1985).

A bar graph of dose rates at Rockville for the 19 days near the autumnal equinox is shown in Fig. 2(b). On this graph about 13 squares are covered by the bars, representing 1170 J/m² (3.3 MED) in the afternoon and a mean of 2340 (6.6 MED) for the average September day at Rockville. The average time of the 45° sun is 1.45 h after local noon, and the number of squares to the right of 1.45 h is 6.4, equivalent to 1.6 MED as defined above. In contrast to mid summer, at the autumnal equinox, the total effective UV-B dose at solar zenith distances less than 45° equals that obtained during the remainder of the day.

DISCUSSION

The dose rate estimates obtained in this study are subject to truncation error in the discrete-valued numerical integration of the convolution of UV-B irradiance and relative erythemal action spectra evaluated at 5-nm resolution. This error is aggravated by the great variation of each of these quantities with wavelength. The values of these UV-B intensities and the CIE relative erythemal action spectrum, however, vary in almost an inverse relationship with each other with the result that their products change by only an order of magnitude in the UV-B band (see Table 1). The magnitude of this type of error is probably not more than a few percent. Another source of error is in the tails of the convolution curve that are not computed, but the sum of the products at 295 and 325 nm is only 6% of the total in Table 1. Therefore, the area under any convolution curve beyond these bands is probably much less than that.

The numerical results in this paper are also subject to errors in the assumptions used in the analysis such as the adopted rate of decrease in erythemal effect with increasing wavelength and the estimates of MED values for individuals of various skin types. The ratios computed here (*e.g.* SPF) are, however, much less sensitive to errors in these assumptions than are the dimensioned values (*e.g.* dose rates).

Measuring irradiances in the UV-B band is very difficult, and the sources of error are too numerous to mention here. SERC scientists, however, use great care to obtain the most accurate observations

possible at the present state of the art. The radiometer's detectors and their interference filters are frequently calibrated and changed if necessary. These radiometers have diffusers that abide by the cosine law to within 2% for zenith angles up to 80° (D. Hayes, Jr., personal communication). Corrections to the data are still being made, such as better determinations of the effective wavelengths of the filters, but it is felt that the accuracy of the preliminary observations used here is adequate for the purposes of the present study.

The estimation of UV-B dose rates can be improved by use of higher resolution UV radiometers that provide data in more ultraviolet bands of narrower bandwidth. SERC is now developing a radiometer that will measure and record UV-B in 18 2-nm half-power bandwidth bands (D. Hayes, Jr., personal communication). This resolution would greatly reduce the truncation error in the convolution of action spectra and UV-B irradiances described above. Finally, the dose rate curves against zenith angle and time of day can be improved by obtaining UV-B observations that are averaged over shorter periods than the 1-h interval used here.

REFERENCES

Dahlback, A., T. Henriksen, S. H. H. Larsen and K. Stamnes (1989) Biological UV-doses and the effect of an ozone layer depletion. *Photochem. Photobiol.* **49**, 621–625.
Goldberg, B. (1982) Radiometric measurements in the UV-B region of daylight. In *The Role of Solar Ultraviolet in Marine Ecosystems* (Edited by J. Calkins), pp. 121–129. Plenum, New York.
Goldberg, B. (1986) The solar ultraviolet, a brief review. In *Advances in Solar Energy*, (Edited by K. W. Boer) Vol. 3, Ch. 6, pp. 357–386. Plenum, New York.
Henriksen, T., A. Dahlback, S. H. H. Larsen and J. Moan (1990) Ultraviolet-radiation and skin cancer. Effect of an ozone layer depletion. *Photochem. Photobiol.* **51**, 579–582.
Holloway, L. (1987) Summer solstice: a part of history but it may be hazardous to your health. *The Hardwick Gazette* (Hardwick, VT, USA) **98**, No. 23, p. 4.
Holloway, L. (1990) Shadow method for sun protection. *The Lancet* **335**, 484.
London, J. (1985) The observed distribution of atmospheric ozone and its variations. In *Ozone in the Free Atmosphere* (Edited by R. C. Whitten and S. S. Prasad), Ch. 1, pp. 11–80. Van Nostrand Reinhold, New York.
Luther, F. M. (1985) Climatic and biological effects. In *Ozone in the Free Atmosphere* (Edited by R. C. Whitten and S. S. Prasad), Ch. 6, pp. 243–282. Van Nostrand Reinhold, New York.
McKinlay, A. F. and B. L. Diffey (1987) A reference

spectrum for ultraviolet induced erythema in human skin. *CIE-J.* **6**, 17–22.

Nautical Almanac Office of the US Naval Observatory (1990) *The Astronomical Almanac for the Year 1990*, p. C24, Supt. of Documents, US Government Printing Office, Washington, D.C.

NOAA, (1984–1988) *Local Climatological Data* (Monthly summary for Washington National Airport), National Climatic Data Center, Asheville, NC.

Parrish, J. A., R. R. Anderson, F. Urbach and D. Pitts (1978) *UV-A: Biological Effects of Ultraviolet Radiation with Emphasis on Human Responses to Longwave Ultraviolet*. Plenum Press, New York.

Pathak, M. A., T. B. Fitzpatrick, F. Greiter and E. W.

Kraus (1978) Preventive treatment of sunburn, dermatoheliosis, and skin cancer with sun protective agents. In *Dermatology in General Medicine, 3rd edition* (Edited by T. B. Fitzpatrick, A. Z. Eisen, K. Wolff, I. M. Freedberg, K. F. Austen.), Ch. 130, pp. 1507–1522. McGraw–Hill, New York.

Scotto, J., G. Cotton, F. Urbach, D. Berger and T. Fears (1988) Biologically effective ultraviolet radiation: surface measurements in the United States, 1974 to 1985. *Science* **239**, 762–764.

Smithsonian Institution, Smithsonian Environmental Research Center, Solar Radiation Laboratory (1989) *Rockville, MD UV-B Data Files*, Jan. 1975 to Oct. 1986 and Sept. 1987 to Dec. 1988, (Available on 13 IBM PC compatible floppy disks.), Edgewater, MD 21037.