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# CALCULATION OF ERYTHEMAL DOSE ON INDIAN SUB-CONTINENT

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An attempt has been made to calculate direct, diffuse and global solar ultraviolet radiation (280nm to 340nm) reaching the ground over Indian sub-continent. Calculations are made for different solar zenith angles taking a standard concentration of aerosols and variable total ozone content (0.250-0.340 atm-cm) in the atmosphere. Analytical representation of biological action spectra is made use of in calculation of effective erythemal dose at different hours of the day. The pupose of this paper is to provide a preliminary information on effective erythemal dose received in different parts of India throughout the year.

**Keywords: Erythemal Dose; Ultraviolet Radiation; Ozone**

## INTRODUCTION

IN recent years, there has been growing concern over the possible impact of man's activities on the environment. Among these the threat of reduction of ozone in atmosphere is the uppermost. Reduction in ozone may cause more ultraviolet radiation from the sun reaching the earth in the wavelength of Hartley and Huggins absorption bands. These wavelengths are of interest because of the potential biological impact of these radiations. To determine the biological effect of middle ultraviolet radiation, it is necessary to know the action spectrum, that is, the relative response of a biological specimen to UV radiation as a function of wavelength. The spectrum of Erythemal or Sunburn producing action of UV radiation for caucasian skin is well documented by Johnson *et al.* (1968).

To calculate the erythemal dose the basic data required are:

(*i*) incoming solar ultraviolet radiation as a function of wavelength;

(*ii*) ozone concentration in the atmosphere;

(*iii*) zenith angle of the sun; and

(*iv*) particulate concentration in the atmosphere.

The calculation of solar UV-B radiation arriving at ground have been undertaken by several groups amongth notable are Cutchis (1974), Green *et al.* (1974, 1976) Shettle and Green (1974), Dave and Furukawa (1966) and a series of calculations by Dave and his group, Dave (1972), Braslau and Dave (1973), Dave (1974), Dave and Braslau (1975), Dave and Canosa (1974), Dave and Halpern (1975), Halpern *et al.* (1974) and Dave and Halpern (1976). The amount of total ozone was taken 0.341 atm-cm by Cutchis, Dave and Furukawa took 0.342 atm-cm, Braslau and Dave took 0.318 atm-cm, Dave and Halpern took 0.200, 0.250, 0.300, 0.350, 0.400 and 0.450 atm-cm and Shettle and Green made calculation at three values of total ozone concentration, namely, 0.16, 0.24 and 0.32 atm-cm. These total ozone concentrations are not suitable for the Indian atmosphere. In the present calculation averaged seasonal values of ozone at Delhi, Kodaikanal and Srinagar as measured by India Meteorological Department have been taken. The UV radiation reaching the ground for various solar zenith angles have been calculated using these averaged value being representative of ozone concentration over the Indian sub-continent.

## Calculation of Direct, Diffuse and Total Solar UV Radiation

The semi-empirical equation derived by Green *et al.* (1974) nearly gives a result similar to more time consuming programming of Braslau and Dave (1973). In the present computation the semi-empirical equation of Green *et al.* (1974) has been used. The direct radiation at solar zenith angle ($\chi$) and wavelength ($\lambda$) reaching the ground can be expressed as :

$$B(\theta, \lambda) = H(\lambda) \cos\theta \exp[-A_t(\theta, \lambda)] \qquad ...(1)$$

where $H(\lambda)$ is the solar radiation at wavelength $\lambda$ above the earth's atmosphere. $H(\lambda)$ can be represented by a linear relationship:

$$H(\lambda) = K[1 + (\lambda - \lambda_0)/d] \qquad ...(2)$$

where $K = 0.522$ w/m$^2$nm; $d = 37$ nm and $\lambda_0 = 300$ nm.

The expression for $A_t(\theta, \lambda)$ is given as:

$$A_t(\theta, \lambda) = W_{oz}K_{oz} \exp[-(\lambda - \lambda_0)/d_0] \,\mathrm{Seq}_{oz}(\theta) + W_a K_a(\lambda_0/\lambda)^{V_a} \,\mathrm{Seq}_a(\theta) + W_p K_p(\lambda_0/\lambda)^{V_p} \,\mathrm{Seq}_p(\theta)$$

$$\mathrm{Seq}_i(\theta) = [1 - \sin^2\theta/q_i]^{-1/2}; \; q_i = (1 + Y_i/R^2 \qquad ...(3)$$

$Y_i$ is an effective altitude of $i$th species and $R$ is the radius of earth. $W_{oz}$ is ozone concentration, $W_a$ is air concentration and $W_p$ is particulate concentration in the atmosphere. In the present computation, $W_{oz}$ has been taken from 0.250 atm-cm to 0.340 atm-cm at an interval of 0.005 atm-cm. $W_a$ is the scale height of the earth's atmosphere and its value is about 8.42km at STP. Similarly $W_p$ (scale height of the particulate) for standard atmosphere has been taken 1.58km. This value of $W_p$ varies from place to place depending upon the weather and other climatic conditions. However, in the present calculation, it has been taken constant at all stations. Other empirical constants are:

$K_{oz} = 10\text{cm}^{-1}$; $K_a = 0.145$km; $K_p = 0.260$km

$d_0 = 8$nm ; $V_a = 4.27$; $V_p = 0.576$

$Y_{oz} = 23.5$km; $Y_a = 5.69$km; $Y_p = 1$km

The diffuse radiation $F(\theta, \lambda)$ received at ground can be represented as

$$F(\theta, \lambda) = H(\lambda) \exp[-D(\theta, \lambda)] \qquad \text{...(4)}$$

where $D(\theta, \lambda)$ is given by

$$D(\theta, \lambda) = K'_{oz} \exp [KK_0 W_{oz} - (\lambda - \lambda_0)/\delta \text{ Spec}(\theta)] \times \text{Seq}(\theta, q_1) + K_{ap} \text{ Seq}(\theta, q_2) \qquad \text{...(5)}$$

where $\text{Spec}(\theta) = 1/[1 - \sin^2 \theta/q]^{1/2}$

The empirical constants for diffuse calculation are :

$K_{ap} = 1.255 \quad K'_{oz} = 1.62 \quad K = .240$

$\delta = 7.48 \quad q_1 = 1.10 \quad K_0 = 10$

$q = 1.148 \quad q_2 = 1.32$

the total radiation '$I$' reaching the ground is the sum of direct and diffuse components. It can be expressed as:

$$I_{total} = H(\lambda) [\cos \theta \exp(-A_t(\theta, \lambda)) + \exp(-D(\theta, \lambda))] \qquad \text{...(6)}$$

From equations (1), (4) and (6), direct diffuse and total solar radiation reaching at the ground have been computed for various ozone concentrations from 0.250 atm-cm to 0.340 atm-cm at an interval of 0.005 atm-cm and for zenith angles from 0 to 80° at an interval of 10°. The UV-B radiation has been calculated for wavelengths 280nm to 340nm at the interval of 2nm. The results of these calculation are presented in subsequent sections.

## Direct and Diffuse Solar Radiation

The direct component of solar radiation received at the ground for different zenith angles at 290nm, 300nm, 310nm and 320nm wavelengths having ozone concentrations of 250, 280 and 300 DU in the atmosphere are presented in Fig. 1. From Fig. 1, it can be seen that with the increase of solar zenith angles the UV radiation decreases but the decrease is very fast after 40° of solar zenith angle and more prominent for shorter wavelengths. The decrease in UV radiation at higher wavelengths with the increase of ozone content is less pronounced due to smaller absorption coefficient. One hardly can see any appreciable effect after 320nm wavelength due to change in ozone content.

In Fig. 2, diffuse radiation *vs.* zenith angle for 290nm, 300nm, 310nm and 320nm with ozone concentration of 250 DU, 280 DU and 300 DU are plotted. It can be seen that the decrease in UV radiation with zenith angle is slower compared to the direct radiation shown in Fig. 1. The variation with zenith angle is 5 order of magnitude for direct radiation, and is only two order of magnitude for diffuse radiation from 0° zenith angle to 80° zenith angle. Therefore, it is suggested that the radiation measurement at higher zenith angles may be taken for scattered radiation. In order to calculate erythemal dose, the direct and diffuse solar radiations reaching at ground have been added to give the total radiation. The integrated total

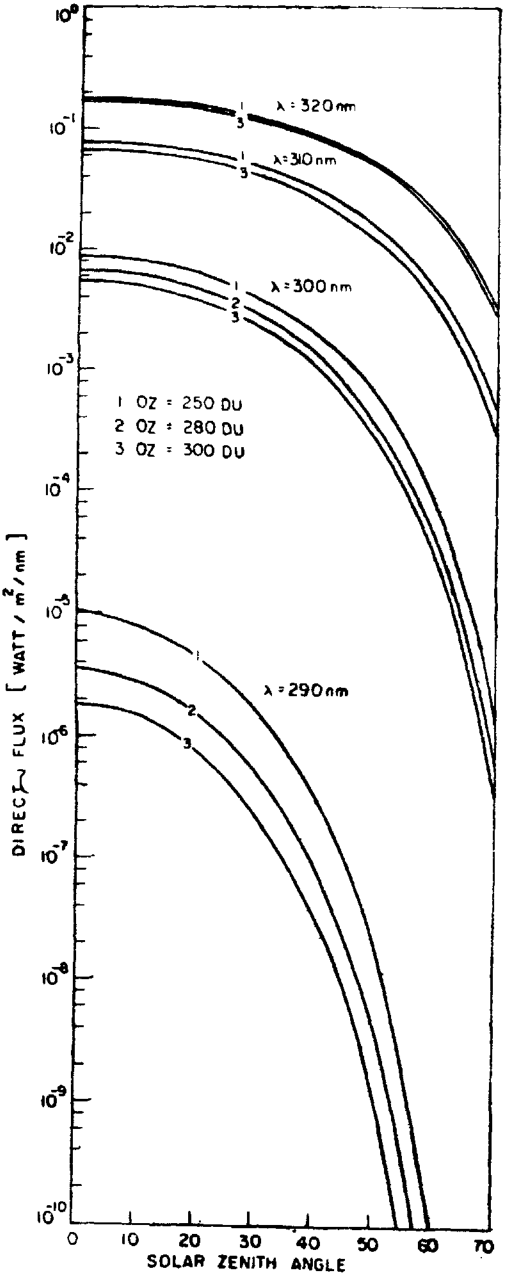


FIG. 1. Variation of direct solar radiation with solar zenith angle at wavelength 290nm, 300nm 310nm and 320nm for ozone concentration of 250 DU, 280 DU and 300 DU.

radiation for each calendar months over Delhi (28°38'N, 77°13'E) and Kodaikanal (10°14'N, 77°29'E) are shown in Figs. 3 and 4 respectively.

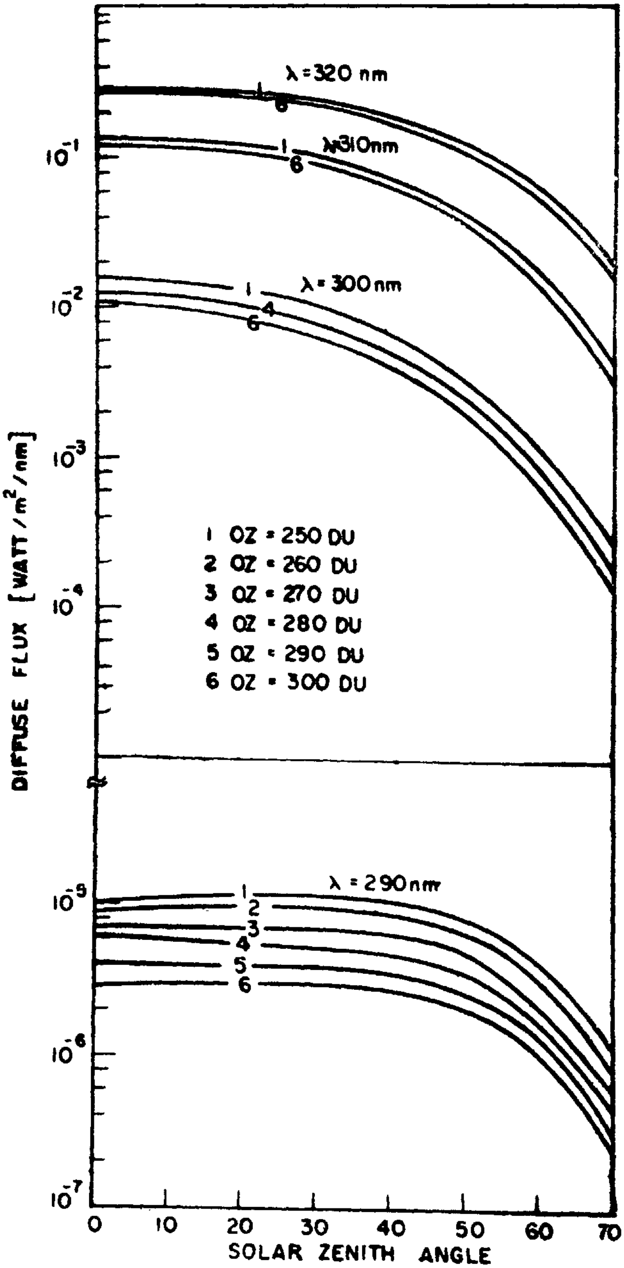


FIG. 2. Variation of diffuse solar radiation with solar zenith angle at 290nm, 300nm, 310nm and 320nm for different ozone concentration.

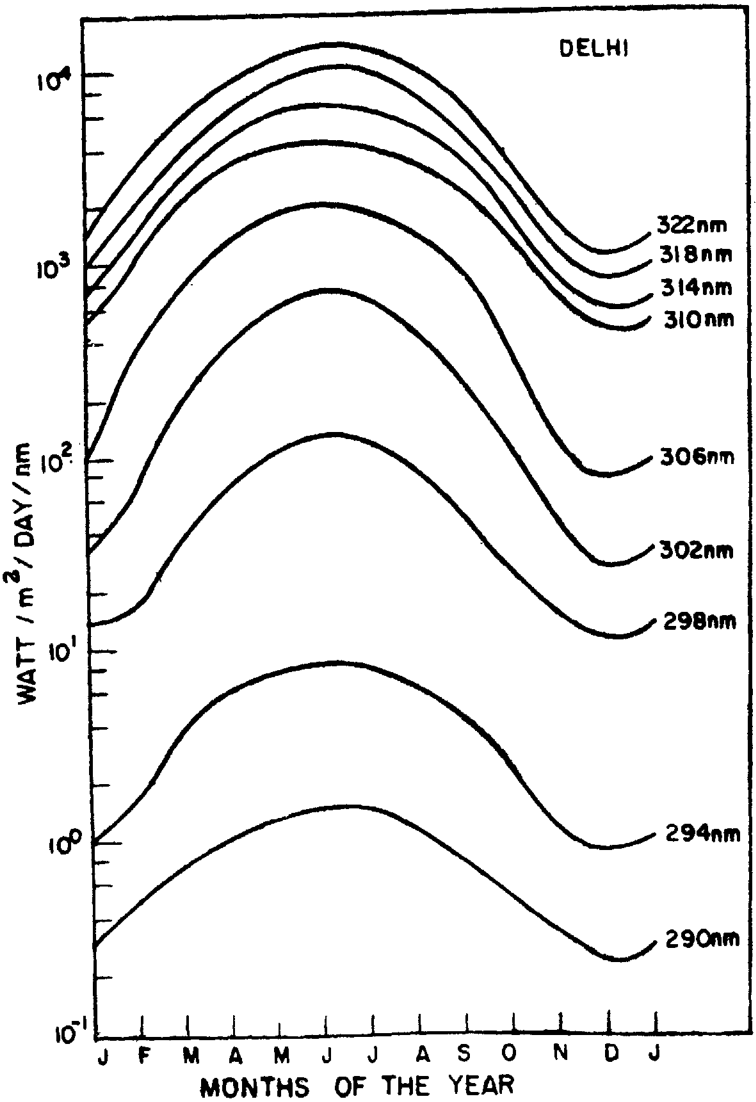


FIG. 3. Monthly variation of total radiation at different wavelengths at Delhi.

*Total Radiation*

Total radiation for Delhi and Kodaikanal for different seasons of the year have been calculated taking the averaged values of ozone for winter, equinoxes and summer months. The ozone concentration for Delhi are 280 DU, 290 DU and 295 DU respectively for winter, equinoxes and summer months. For Kodaikanal, the average seasonal values of ozone for winter, equinoxes and summer months are 265DU, 270DU and 285DU, respectively. Taking these values of ozone, UV radiation at various wavelengths reaching at the ground are computed and the daily total

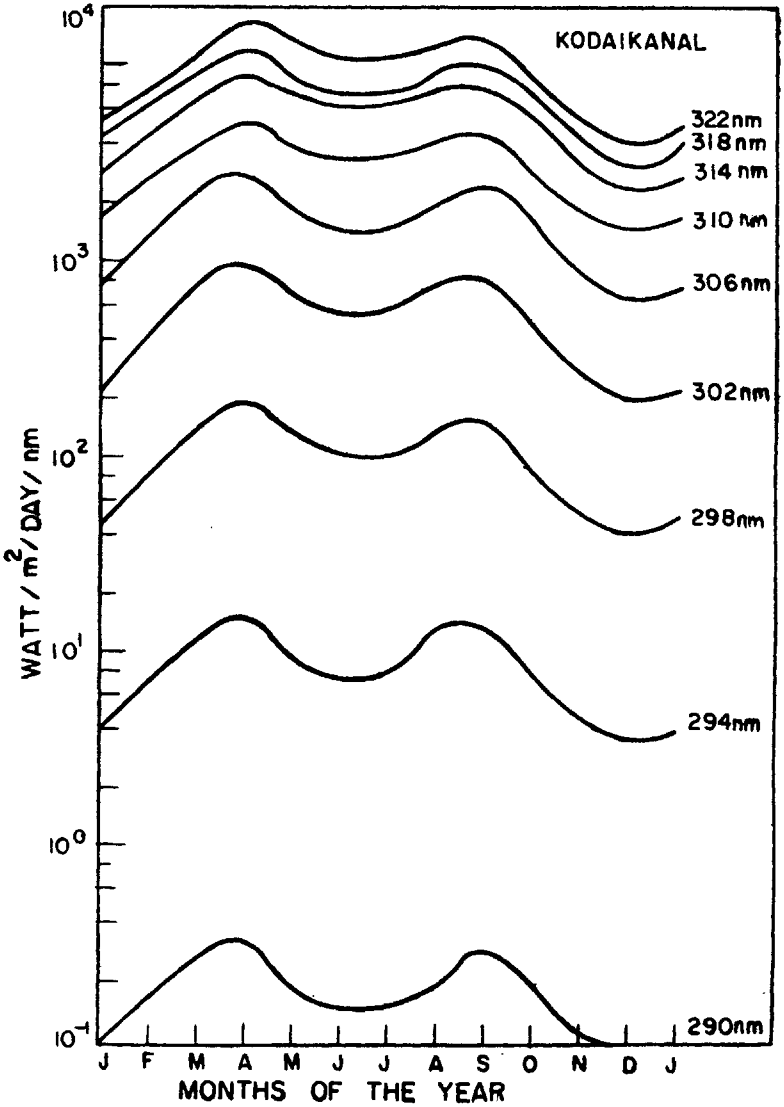


FIG. 4. Monthly variation of total radiation at different wavelengths at Kodaikanal.

radiation are then integrated for entire month. In Figs. 3 and 4, monthly integrated values at different wavelengths are presented over Delhi and Kodaikanal, respectively. The UV radiation has been plotted in unit of watt/m$^2$/day for each month. As expected, the radiation is minimum during winter months and maximum during summer months for Delhi. However, from Fig. 4, it is clear that the radiation at Kodaikanal is maximum during equinoxes rather than during summer months. One can estimate average UV radiation for any day of the month from these two curves by dividing monthly value by number of days in a month.

*Minimum Perceptible Erythemal Dose*

The effects of UV radiation vary with the change of wavelength and such changes are known as action spectra of UV radiation. The action spectra of UV-B radiation is given in Fig. 5 as reported by Caldwell (1971). The product of UV radiation and the value of action spectra at a certain wavelength determines the relative effect of various wavelengths' radiation. This product can be represented in terms of perceptible erythemal dose. The effect due to this dose can be classified depending upon the amount of perceptible erythema. The minimum perceptible erythema (MPE) which can affect biologically human skin is defined in terms of 1 unit having the energy of $2.5 \times 10^5$ ergs/cm$^2$.

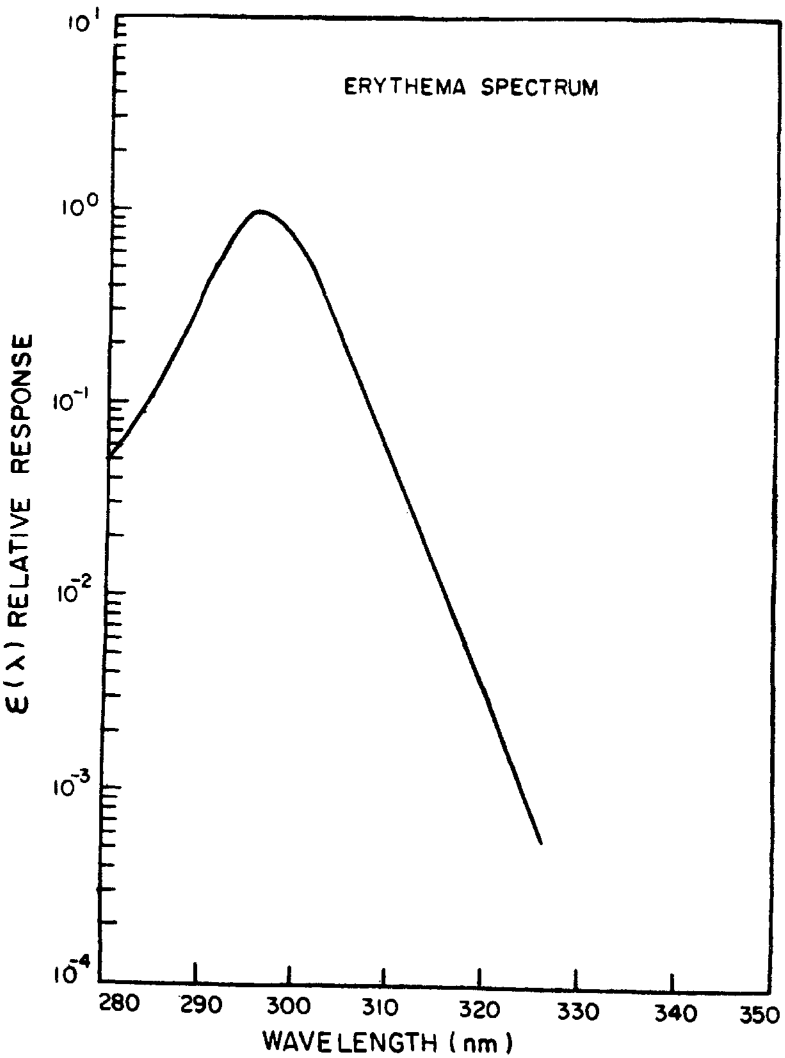


FIG. 5. Action spectra of UV-B radiation.

In order to calculate the total perceptible erythema, first the product of hourly integrated UV radiation at a particular wavelength and its action spectra were determined. These products are further integrated over the entire wavelength region of UV-B covering from 290nm to 320nm radiation to estimate hourly values of MPE due to UV radiation. This total integrated value on hourly basis for the different months of a year are plotted in Figs. 6 to 8 for the Delhi, Kodaikanal and Srinagar respectively.

As seen from Fig. 6, the maximum MPE at Delhi is 3 during summer months between 10 to 13 hours. In equinoxes, the maximum value is 2 from 0900 to 1330 hours. In winter, the MPE value is very small and is always less than unity. In Delhi, there will be no adverse effect on human skin due to solar ultraviolet radiation in the month of January to March and from October to December when MPE value is less than two with present estimates. However, from April to September it can cause sunburn if body is exposed to longer duration in the sun, and in fact it does especially in months of May, June and July.

From Fig. 7, it is clear that there is a marked difference in MPE between Delhi and Kodaikanal. At Kodaikanal, the maximum value of MPE is 4 while it is only 3 at Delhi. The maximum value of MPE for Kodaikanal is not in the month of June as in the case of Delhi but it is in months of April and September between 10 to 12 hours. For the rest of the months the MPE is 3 during 10 to 13 hours. 2 MPE remains round the year from 9 to 14 hours.

From the contour plots of MPE in Fig. 8 for Srinagar (34.05°N, 74.50°E) one can see that the maximum value of MPE is only 2.5 unit from mid May to mid June. 2 MPE is available during summer months. In months of equinoxes its value is only

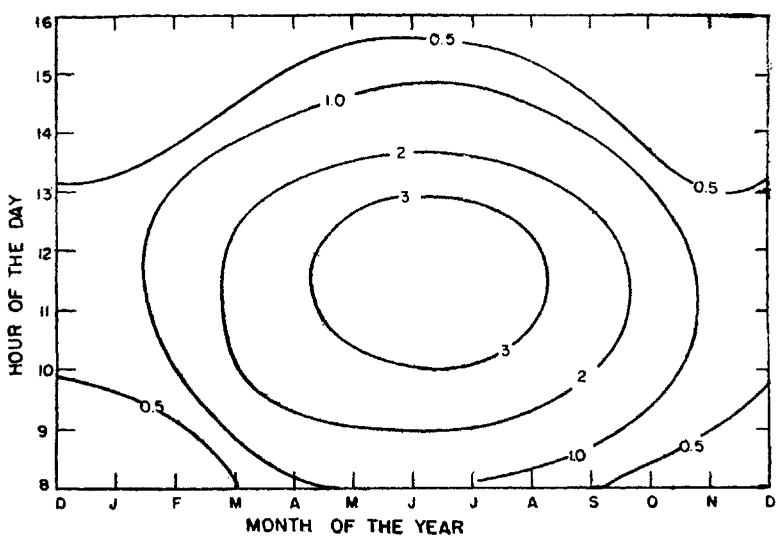


FIG. 6. Contour plots of MPE (Minimum Perceptible Erythemal dose) at Delhi.

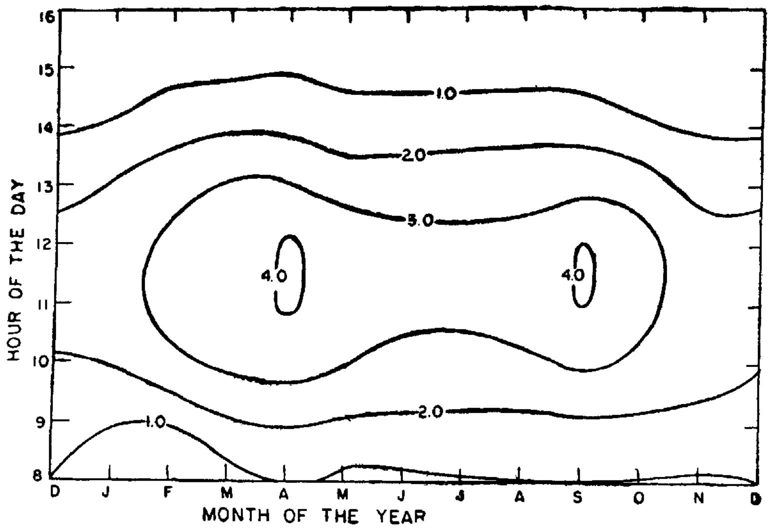


FIG. 7. Contour plots of MPE (Minimum Perceptible Erythemal dose) at Kodaikanal.

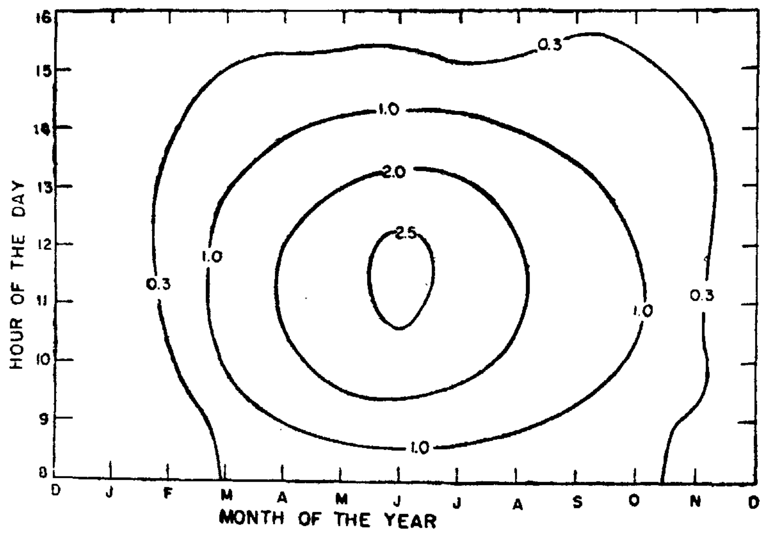


FIG. 8. Contour plots of MPE (Minimum Perceptible Erythemal dose) at Srinagar.

one. On the basis of MPE values at Srinagar, very little effect of UV radiation is seen on human skin.

The variation in MPE dose at Srinagar, Delhi and Kodaikanal is due to the fact that these stations are located from 34.05°N latitude to 10.02°N latitudes and ozone contents at Srinagar is maximum and minimum at Kodaikanal. The sunshine hours also vary from place to place. At Srinagar, the sunrays are more oblique than at Kodaikanal round the year giving place to more absorption. Due to higher ozone content and larger absorption path length, the net result is that the absorption of UV radiation at Srinagar is much higher than at Kodaikanal resulting less UV radiation reaching at the ground in Srinagar. From this one can infer that the equatorial regions receive more erythemal dose in comparison to higher latitude regions.

From these contour plots, we see that the adverse effect of solar UV radiation are possible only at low latitudes like Kodaikanal, Trivandrum and Madras. At mid latitudes namely Delhi, Allahabad and Varanasi, the UV effect can only be felt during summer months. At Srinagar the effect is negligible.

*Erythemal Dose*

The integrated value of perceptible erythema for a complete year available at any place is generally represented as a erythemal dose at that place and its unit is Mega Joules per meter square per year ($MJ/m^2y$). The erythemal dose for Delhi, Kodaikanal and Srinagar has been calculated from hourly MPE value available in different months. The calculated value for different months are tabulated in Table I. In this calculation no account has been taken of cloud, wind, and other weather conditions. This estimation has been done assuming clear atmosphere without any disturbance throughout the year. However, weather conditions can reduce these values appreciably and thus the value given in Table I are the maximum values for any place. Similar calculation can be carried out for any other station provided ozone concentrations are known.

TABLE I

*Solar UV-B monthly perceptible erythema and yearly erythemal dose*

| Month | Kodaikanal | | Delhi | | Srinagar | |
|---|---|---|---|---|---|---|
| January | 0.063 $MJ/m^2$/month | | 0.026 $MJ/m^2$/month | | 0.006 $MJ/m^2$/month | |
| February | 0.099 | ,, | 0.062 | ,, | 0.012 | ,, |
| March | 0.160 | ,, | 0.099 | ,, | 0.027 | ,, |
| April | 0.207 | ,, | 0.130 | ,, | 0.091 | ,, |
| May | 0.147 | ,, | 0.156 | ,, | 0.101 | ,, |
| June | 0.118 | ,, | 0.157 | ,, | 0.101 | ,, |
| July | 0.121 | ,, | 0.157 | ,, | 0.100 | ,, |
| August | 0.166 | ,, | 0.108 | ,, | 0.070 | ,, |
| September | 0.178 | ,, | 0.077 | ,, | 0.041 | ,, |
| October | 0.105 | ,, | 0.040 | ,, | 0.027 | ,, |
| November | 0.061 | ,, | 0.051 | ,, | 0.012 | ,, |
| December | 0.053 | ,, | 0.012 | ,, | 0.006 | ,, |
| Yearly value : | 1.479($MJ/m^2y$) | | 0.765($MJ/m^2y$) | | 0.556($MJ/m^2y$) | |

## CONCLUSION

This study of solar UV-B radiation, MPE and erythemal doses at different places at various hours of the day, monthly and yearly basis provide ready estimates of this biologically effective region of solar radiation. These contours and a spot value of radiation are needed by medical professionals for the treatment of certain type of ailment. Also it provides a basic input for the bioscientists who are interested in study of plant behaviours under the effect of UV radiations.

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