A simple technique for estimating daily ambient erythemal ultraviolet from the ultraviolet index

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Summary

A simple method is described that allows the estimation of daily ambient erythemal ultraviolet exposure from the ultraviolet index. The estimation can be performed quickly using only a calculator (or even mental arithmetic) and is applicable in those situations where access to computers and the internet is not feasible.

Key words:
maximum daily exposure; standard erythema dose; UV index

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The solar ultraviolet index (UVI) is a well-established vehicle to raise public awareness and provide information to the public about the potential detrimental effects on health from solar ultraviolet (UV) exposure (1, 2). In recent years, the UVI has appeared on TV weather forecasts and internet websites in many countries to provide the public with a guide to the maximum intensity of the sun's UV rays (see, e.g., http://exp-studies.tor.ec.gc.ca/cgi-bin/uv_index_calculator).

The UVI is a measure of erythemal UV at the Earth's surface and is expressed numerically as the equivalent of multiplying the time-weighted average erythemal-effective irradiance (in W/m^2) by 40, and refers to the daily maximum effective irradiance at the Earth's surface averaged over a duration of between 10 and 30 min (1).

For southern cities in Australia, such as Melbourne (37.8°S) and Sydney (33.9°S), the measured UVI is maximal during summer (December–February), with UVI regularly reaching values of 12. In more northerly Australian cities such as Darwin (12.4°S), the maximum UVI can reach 16 (3). In summer in Europe, the UVI typically peaks at values from 5 at high latitudes (∼60°N, e.g. Scandinavia) to around 7 in central regions (∼50°N, e.g. southern UK, Belgium, northern France), and up to 9 or 10 in southern Europe (∼40°N, e.g. southern Spain). In the United States, the maximum UVI ranges from 11 in the southern continental United States to 5 in Alaska, whereas in Canada peak values reach 8 in the southern cities.

Although the UVI is a measure of UV intensity, it is the cumulative dose during the course of a day that is important for human exposure and any subsequent cutaneous damage. As a measure of erythemal exposure, the CIE has introduced the concept of a standard erythemal dose (SED), where 1 SED is defined as 100 J/m^2 of erythemal-effective UV radiation (4).

It is possible to calculate the daily erythemal UV by complex radiative-transfer models (5, 6) and web-based tools are available to achieve this (http://www.temis.nl/uvradiation/, http://nadir.nilu.no/∼olaeng/fastrt/fastrt.html). However, it can sometimes be useful to estimate the ambient erythemal UV (in SED) from the forecast UVI without the need to access the internet or even use a computer. A simple method is presented here to achieve this goal. The method is most accurate for days when there is no cloud cover, which are those days that have the potential to cause maximum biological damage. On days when there is cloud cover, especially variable cloud cover during the day, the estimate is only approximate, as is the case with more sophisticated radiative transfer models.

Method

In order to maintain a simple approach that does not involve complex calculations requiring a computer, the method presented here assumes that the irradiance of solar erythemal

Table 1. Daylength in hours for the mid-point of each month

Month	Latitude 60°S	50°S	40°S	30°S	20°S	10°S	0°	10°N	20°N	30°N	40°N	50°N	60°N
Jan	17.6	15.7	14.5	13.7	13.1	12.5	12.0	11.5	10.9	10.3	9.5	8.3	6.4
Feb	15.3	14.2	13.6	13.1	12.7	12.3	12.0	11.7	11.3	10.9	10.4	9.7	8.7
Mar	12.6	12.4	12.3	12.2	12.1	12.1	12.0	11.9	11.9	11.8	11.7	11.6	11.4
Apr	9.8	10.5	10.9	11.3	11.5	11.8	12.0	12.2	12.5	12.7	13.1	13.5	14.2
May	7.1	8.8	9.8	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.2	15.2	16.8
Jun	5.6	7.9	9.2	10.1	10.8	11.4	12.0	12.6	13.2	13.9	14.8	16.1	18.4
Jul	6.3	8.3	9.4	10.3	10.9	11.5	12.0	12.5	13.1	13.8	14.6	15.7	17.7
Aug	8.7	9.8	10.4	10.9	11.3	11.7	12.0	12.3	12.7	13.1	13.6	14.3	15.3
Sep	11.5	11.6	11.7	11.8	11.9	11.9	12.0	12.1	12.1	12.2	12.3	12.4	12.6
Oct	14.3	13.6	13.1	12.8	12.5	12.2	12.0	11.8	11.5	11.3	10.9	10.4	9.7
Nov	16.9	15.3	14.3	13.5	13.0	12.5	12.0	11.5	11.0	10.5	9.8	8.8	7.1
Dec	18.4	16.1	14.8	13.9	13.2	12.6	12.0	11.4	10.8	10.1	9.2	7.9	5.6

UV exhibits a Gaussian distribution between sunrise and sunset, peaking at solar noon (the time of maximum UVI), an assumption that is well supported by the diurnal variation of erythemal UV at different latitudes (7).

Hence, the daily ambient erythemal UV (in SED) can be calculated as:

$$\left\{\mathrm{UVI}/40 \times [3600 \times \mathrm{H}/5]\sqrt{2\pi}\right\}/100 \qquad (1)$$

Or, more simply, daily ambient erythemal

$$\mathrm{UV} = 0.45 \times \mathrm{UVI} \times H\,(\mathrm{SED}) \qquad (2)$$

where H is the hours of daylight for the date and latitude of interest. This can be calculated using an established astronomical equation, which is as follows:

$$H = 24 \times \cos^{-1}(1 - (1\tan(L) \times \tan(0.409088 \times \cos(0.0172024 \times \mathrm{DN}))))/\pi \qquad (3)$$

where L is the latitude expressed in radians and DN is the day number, where DN = 0 for 21 December (northern hemisphere) and 21 June (southern hemisphere). Hence, e.g., DN = 25 on 15 January for locations in the northern hemisphere and DN = 206 on the same date for locations in the southern hemisphere. The values of H are given in Table 1 for the mid-point of each month and a range of latitudes.

In the model used here, it is assumed that that the daylength (H) extends over ± 2.5 standard deviations of the diurnal variation of irradiance, which accounts for the factor of 5 in the denominator of the second term in Equation (1).

Results

Table 2 shows the maximum daily ambient erythemal UV calculated using Equation (2) and the relevant entries in Table 1 for mid-June in the northern hemisphere. As can be seen from Table 2, these values are in close agreement with those obtained using a much more complex model (6).

From Table 2, the maximum ambient daily UV in mid-summer in southern Europe (~40°N), for example, is around 60 SED. This exposure would not be received by people simply because it would be unrealistic to lie in the unshaded sun all day without moving. An extreme sunbather might spend half their time supine and half the time prone, resulting in a maximum exposure on much of the body surface of 50% of ambient. For upright subjects engaging in a variety of outdoor pursuits such as gardening, walking or sport, the exposure relative to ambient on commonly exposed sites, e.g. chest, shoulder, face, forearms and lower legs, ranges from about 20% to 60% (8). Thus, someone who is on vacation in southern Europe, for example, would receive a daily exposure of no more than 20 SED over much of the body surface, and this equates to about 7 MED on the previously unexposed skin of melano-compromised people who do not tolerate the sun well and burn easily (9). Even for all-day sunbathing in the tropics, where the maximum daily ambient UV is about 70 SED (Table 2), cutaneous exposure in people with the same skin type is not likely to exceed the equivalent of about 12 MED.

Table 2. Estimated maximum daily ambient erythemal UV for mid-June (northern hemisphere) calculated by the present method and by a complex radiative transfer model (6)

Latitude	Maximum UVI	Daylength (h)	Maximum daily ambient UV (SED) This method	Radiative transfer*
60°N	5	18.4	41	38
50°N	7	16.1	51	48
40°N	9	14.8	60	58
30°N	11	13.9	69	66
20°N	12	13.2	71	70

*See http://nadir.nilu.no/~olaeng/fastrt/fastrt.html. Data were calculated for a cloudless sky at sea level assuming a longitude of 0°, visibility of 350 km and surface albedo of 0.03. Values used for total ozone column were the mean monthly amount around each latitude circle in the northern hemisphere (10).

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