Solar UVA exposures

Alfio V. Parisi[a,*] and Michael G. Kimlin[b]

[a]Centre for Astronomy, Solar Radiation and Climate, Faculty of Sciences, University of Southern Queensland, Toowoomba, AUSTRALIA. 4350

[b]Centre for Health Research, School of Public Health, Queensland University of Technology, Brisbane, QLD, AUSTRALIA.

ABSTRACT

Exposures to UVA radiation (320 – 400 nm) have been linked to increasing the risk of skin cancer, premature skin photoageing and skin wrinkling. The relative proportion of the UVA irradiances in the solar spectrum changes with time of day and season. Material such as window glass found in offices, homes and motor vehicles acts as a barrier to the shorter solar UVB wavelengths (280 - 320 nm) and transmits some of the longer UVA wavelengths (dependent on the type of glass). As a result, the spectrum of the filtered UV transmitted through the material may be substantially different from that of the unfiltered solar UV spectrum. This results in a change in the relative ratio of UVA to UVB irradiances and a consequent change in the biologically damaging UV exposures. For these environments where the UVB wavelengths have been removed and the UVA wavelengths are still present, it is necessary to consider the erythemal irradiances due to these UVA wavelengths only. This paper investigates the times taken for an exposure of 1 SED (standard erythemal dose) due to the UVA wavelengths.

Keywords: UVA, solar, filtered, glass

1. INTRODUCTION

The importance of the UVA wavelengths (320 - 400 nm) for the production of mutations in the basal cell layer of human skin has been reported[1]. The implication from this is that the longer UVA wavelengths are a potential carcinogen in human skin. Additionally, the UVA wavelengths have also been shown to cause cumulative damage and premature photoageing of human skin[2-4]. The solar erythemal irradiances due to the UVB wavelengths (280 – 320 nm) are more significant for skin damage as represented by the higher effectiveness of the erythemal action spectrum[5] at these wavelengths compared to the effectiveness at the UVA wavelengths. Although the effectiveness of the erythemal action spectrum is reduced by a factor of approximately 1000 at the UVA wavelengths compared to the most effective wavelength of 298 nm, the erythemal irradiances due to the UVA wavelengths may become important for the cases where the UVB wavelengths have been significantly attenuated.

Environments where the UVB wavelengths can be attenuated arise when the solar UV is transmitted through materials such as the glass found in office windows, home windows and greenhouses and the glass in vehicle windows and windscreens[6]. For untinted glass, the type of glass, thickness of the glass and the angle of transmission of the UV through the glass determines the amount of UV attenuation[7,8]. The laminated window glass of a vehicle's windscreen transmits less than the nonlaminated glass of the side windows[9]. Additionally, whether or not the glass is tinted determines the amount of solar UV transmitted[9-11]. A number of studies have investigated the filtered UV in different environments of cars[12-14], greenhouses[15] and sunrooms[16]. For example, research using a UV spectroradiometer inside a vehicle with untinted windows found that the irradiance of all of the shorter UVB wavelengths were negligible, however the UVA irradiances from 340 nm to 400 nm were significant in the vehicles[10]. Research employing dosimeters for the measurement of the UV exposures in these environments has also been reported[12,17].

[*] Correspondence to: Alfio Parisi, Faculty of Sciences, University of Southern Queensland, Toowoomba, 4350, Australia. parisi@usq.edu.au Ph: 61 7 4631 2226; FAX: 61 7 4631 2721.

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2. MATERIALS AND METHODS

2.1 Spectral UV

The spectral UV measurements on a horizontal plane were undertaken with a UV spectroradiometer (model DTM300, Bentham Instruments, Reading, UK) that is configured to automatically collect data on the UV spectrum from 280 to 400 nm in 0.5 nm increments every five minutes. The instrument is located on an unshaded roof of a building at the University of Southern Queensland, Toowoomba, (27.5 ^{o}S, 693 m above sea level) Australia. This site is an inland sub-tropical southern Hemisphere site with relatively unpolluted skies. The spectroradiometer is housed in an environmentally sealed container (Figure 1) and solar radiation enters via the input optics based on a diffuser (model D6) and connected by a one metre long, 4 mm diameter optical fibre to the input slit of the monochromator. The instrument employs a double grating monochromator with a pair of holographic gratings with 2400 lines/mm blazed at 250 nm and a 600 mm focal length (model DTMc300F), a UV sensitive detector comprising of a side window photomultiplier tube with a bialkali photocathode (model DH10), amplifier with software variable gain (model 267) and integrating analogue to digital converter with 100 ms integration period (model 228A)[18].

Figure 1: Automated solar UV spectroradiometer enclosed in the weatherproof container on an unshaded roof.

The system is configured to scan the UV spectrum every five minutes and each scan takes approximately 2 minutes plus approximately another minute for the initialisation of the scan. The irradiance calibration of the system was against a 150 W quartz tungsten halogen (QTH) lamp calibrated to the National Physical Laboratory, UK standard and the wavelength calibration is against the UV spectral lines of a mercury lamp. On a bi-weekly to monthly basis, the stability and wavelength calibration of the instrument was checked against 150 W QTH lamps and the mercury lamp UV spectral lines respectively[18].

2.2 Erythemal UV

The data reported in this paper considers the spectral UV at five minute intervals in a summer month (January) and in a winter month (July). The range of solar zenith angles (SZA) during the summer measurement period was from approximately 5^o to 80^o and the range during the winter period was approximately 45^o to 80^o. The spectral data, $S(\lambda)$ was weighted with the erythemal action spectrum, $A(\lambda)$[5] at each 0.5 nm to produce the spectral erythemal UV irradiances. These were summed over the UVA wavelengths to produce the erythemal irradiances due to this waveband, UVA_{ery} as follows:

$$UVA_{ery} = \sum_{UVA} A(\lambda) S(\lambda) \Delta\lambda \qquad \text{W m}^{-2}$$

Similarly, the erythemal UV due to the entire UV waveband, UV_{ery} was obtained by summing over the wavelengths of 290 to 400 nm.

At each five minute interval, the time taken to receive an exposure of 1 SED (standard erythemal dose)[19] was calculated for the UVA_{ery} and UV_{ery} irradiances at that point. One SED has been defined as equivalent to an erythemal exposure of 100 J m^{-2}.

3. RESULTS

3.1 Erythemal UVA

The erythemal UV irradiances for January (summer) at five minute intervals are provided in Figure 2 for all of the cloud conditions encountered during this period. These are provided for all of the UV wavelengths and for the UVA wavelengths. In each case, the clear sky envelope is evident with the variation below this being predominantly due to cloud. The number of five minute irradiance data points is 3145. For the UV_{ery}, the maximum is 471 mW m^{-2} and for the UVA_{ery}, the maximum is 59 mW m^{-2}. The atmospheric ozone values in Dobson Units (DU) obtained through the TOMS (Total Ozone Mapping Spectrometer) website (http://toms.gsfc.nasa.gov/ozone/ozone.html) ranged from 257 to 290 DU (Dobson units). The effects of ozone changes on the UVA_{ery} would be insignificant due to the negligible absorption of ozone in the UVA[20].

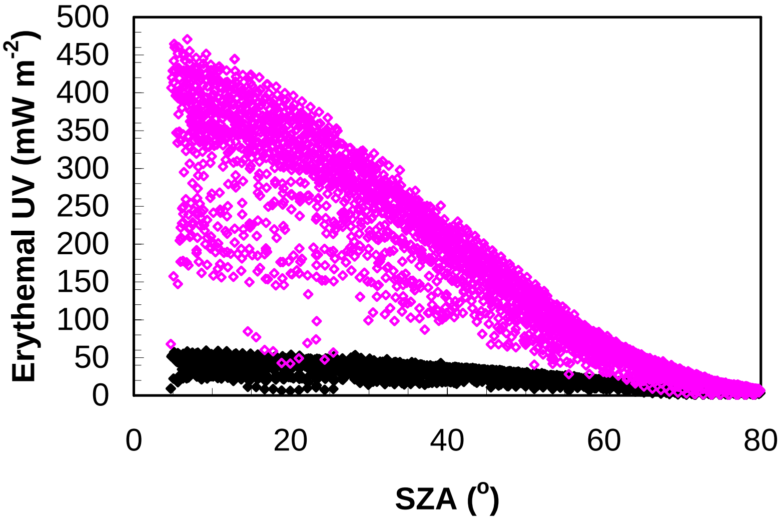


Figure 2: The erythemal UV as a function of SZA in the summer month of January due all the UV wavelengths (◊) and due to the UVA wavelengths (♦).

The comparison between the UVA_{ery} and the UV_{ery} irradiances for the range of SZA encountered in each month is provided in Figure 3 where the ratio of the two irradiances are plotted for all sky conditions. The plot shows the variation with the SZA. For the smaller SZA, the UVA_{ery} is of the order of a tenth of the erythemal UV. In comparison at the larger SZA of 60^o, the UVA_{ery} is of the order of a third of the erythemal UV. At the SZA of 80^o, the UVA_{ery} is of the order of 50 to 60% of the UV_{ery}. This increase in the relative amount of UVA_{ery} compared to UV_{ery} at the higher SZA is due to the higher degree of attenuation of the UVB wavelengths for the longer paths through the atmosphere.

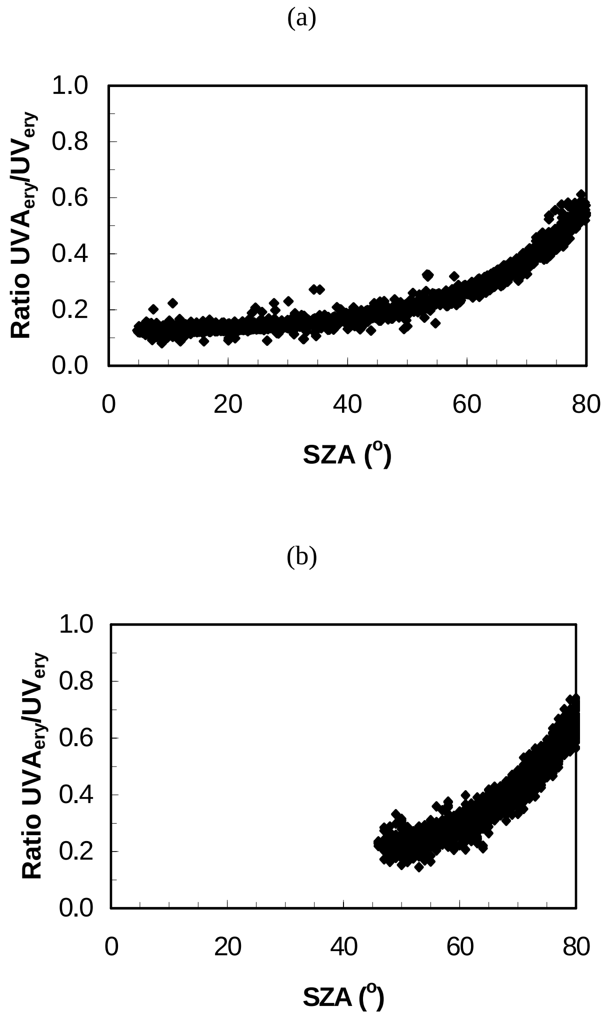
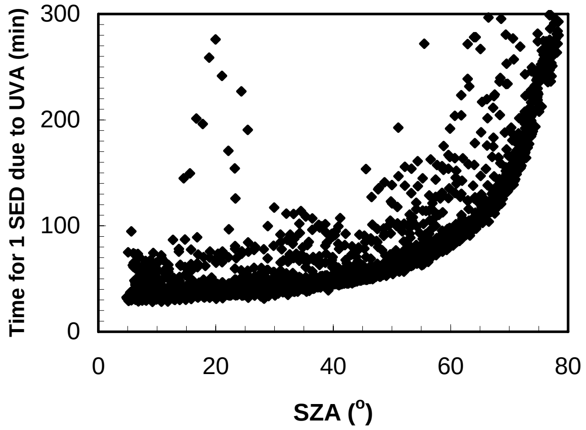


Figure 3: The ratio of the erythemal irradiances due to the UVA wavelengths to those due to the total UV waveband as a function of SZA in (a) January (summer) and (b) July (winter).

3.1 Exposure times for one SED

The times taken for an exposure of 1 SED due to the UVA wavelengths only, on a horizontal plane as a function of SZA in January and July (winter) are provided in Figure 4. In both cases, the times for the cloud free cases at each SZA are represented by the lower value at each SZA. The times higher than this are due to the cases where there is cloud cover during part of or all of the UV spectral scan. For summer the times for an exposure of one SED due to the UVA_{ery} are 28 min and higher. For the winter month where the minimum SZA is 46^o, the times for an exposure of one SED due to the UVA_{ery} are 57 min and higher.

(a)



(b)

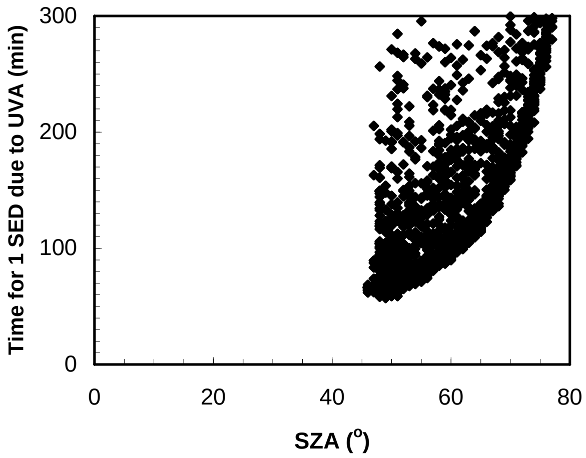
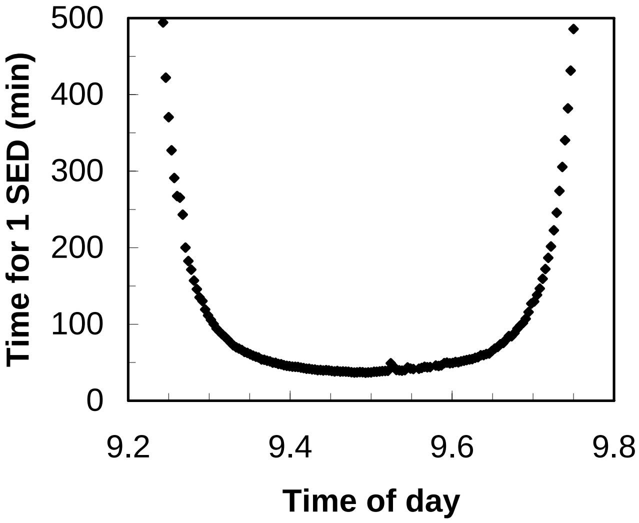


Figure 4: The times taken for an exposure of 1 SED due to the UVA wavelengths only, on a horizontal plane as a function of SZA in (a) January (summer) and (b) July (winter).

The variation throughout the day of the time taken for an exposure of 1 SED due to the UVA_{ery} is provided in Figure 5 for a cloud free day in January and a relatively cloud free day in July. The minimum time for an exposure of 1 SED in January is 37 min and it ranges upwards from this time and in July, this time was approximately 63 min. Either side of noon on the 9 January, the time for one SED is 39 and 40 at 11.00 am and 1.00 pm respectively and 43 and 45 at 10.00 am and 2.00 pm respectively.

(a)



(b)

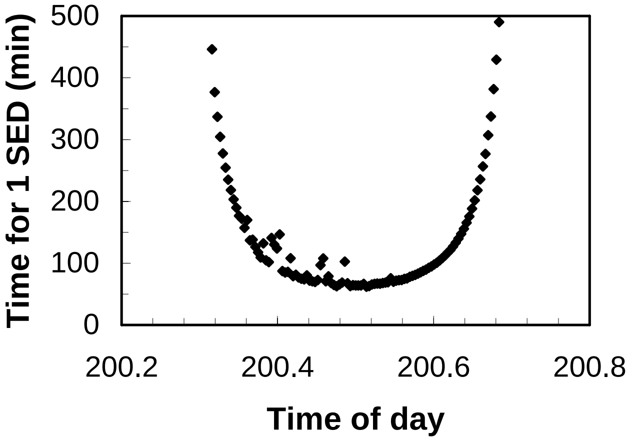


Figure 5: The time for an exposure of 1 SED due to the UVA_{ery} for the different times of the day on the cloud free day of 9 January and the relatively cloud free day of 19 July.

4. DISCUSSION

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For the environments where the UVB wavelengths have been removed and the UVA wavelengths are still present, it is necessary to consider the erythemal irradiances due to the UVA wavelengths only. These environments occur where the solar UV has been transmitted through a transparent barrier such as glass. In order to gain an understanding of the UV exposures in these environments, this paper has reported on the erythemal exposures due to the UVA wavelengths only at a sub-tropical site in a summer month and a winter month. An extensive data set collected at five minute intervals during the day for all weather conditions encountered during the period has been employed.

For the UV_{ery}, the maximum irradiance was 471 mW m^{-2} and for the UVA_{ery}, the maximum was 59 mW m^{-2}. The ratio of the UVA_{ery} to UV_{ery} irradiances varied from approximately 0.1 to 0.6 for the small to larger SZA respectively. The minimum time for an exposure of one SED due to the UVA_{ery} was 27 min and 58 min in the summer and winter respectively. This calculation was based on the assumption that all of the UVA wavelengths are transmitted through the transparent barrier. This is generally not the case, with some attenuation of the UVA wavelengths occurring in the transmission through a barrier, however the results provide an upper limit on the erythemal exposures in these environments. Although the times for an exposure of one SED are reduced compared to those for the entire UV waveband, the exposures due to the UVA wavelengths are important for those population groups that are exposed to these wavelengths for lengthy periods as the results show that for extended periods of time of exposure, it is possible to receive erythemal exposures as a result of the UVA wavelengths. This highlights the importance of the necessity to develop a dosimeter that is sensitive to only the UVA wavelengths to allow the measurement of the UVA exposures to different population groups during normal daily activities.

ACKNOWLEDGMENTS

The research reported in this paper is supported by a US National Institute of Health Grant number R01 CA101602-01A2 and the spectroradiometer was funded by the Australian Research Council.

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