DIFFUSE COMPONENT OF THE SOLAR ULTRAVIOLET RADIATION IN TREE SHADE

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ABSTRACT

This paper has provided the first set of quantitative data of diffuse erythemal UV and UVA in tree shade at a sub-tropical Southern Hemisphere latitude. Over the summer, approximately 60% of the erythemal UV radiation in the tree shade is due to the diffuse component. Similarly, approximately 56% of the UVA radiation in the tree shade is due to the diffuse component. In the tree shade these diffuse UV percentages are relatively constant from the morning to noon to afternoon periods. In comparison, in full sun, there is a decrease in the percentage diffuse UV from morning to noon to afternoon. The exposures to diffuse UV on a horizontal plane in the tree shade between 9:00 EST to 15:00 EST were of the order of 4 MED and 14 J cm^{-2} for erythemal UV and UVA respectively. The high diffuse UV component in the shade may result in high UV exposures to not only parts of the body on a horizontal plane that are not protected, but also, equally high UV irradiances to parts of the body, including the eyes and face, that are not UV protected.

1. INTRODUCTION

Personal UV exposure to humans is due to sunlight received as both direct radiation and diffuse radiation. In full sun, the diffuse component is higher for larger solar zenith angles for similar cloud conditions (Blumthaler et al., 1994). This diffuse radiation may constitute a significant component to the UV exposure received by humans' eyes and skin as it is incident from all directions and difficult to minimise with the usage of hats, tree shade and shade structures as it can reach surfaces shaded from the direct component. Modelling of the diffuse solar irradiances has been previously described (for example, Bird, 1984). Blumthaler and Ambach (1991) have measured the spectral global and diffuse solar ultraviolet radiation. The diffuse UV to global radiation ratio increases with decreasing wavelength due to the stronger Rayleigh scattering at the shorter wavelengths. Ireland and Sacher (1996) have employed radiometers with narrow band interference filters to measure the angular distribution of UV radiation at a Southern Hemisphere site and Blumthaler et al., (1994) have measured the effects of clouds on the diffuse UV irradiances.

This modelling and measurement by previous researchers of the diffuse UV irradiances has been in unshaded sunlight. The UV irradiances in tree shade have been measured (Parisi et al., 1999, Parsons et al., 1998 and Grant, 1997) and under crop canopies (Grant, 1991) and forest canopies (Flint and Caldwell, 1998). In tree shade, a larger proportion of the UV compared to that in full sun may be as a result of the diffuse component due to attenuation and filtering of the direct component. However, no previous research has considered the diffuse UV irradiances in tree shade. This paper presents the results of quantitative measurements of the diffuse erythemal and diffuse UVA (320 to 400 nm) at ground level on a horizontal plane during a Southern Hemisphere sub-tropical summer.

2. MATERIALS AND METHODS

2.1 Irradiance Measurements

The erythemal UV irradiance, UV_{ery} is defined as:

$$UV_{ery} = \int_{UV} S(\lambda) A(\lambda) d\lambda \qquad (1)$$

where S(λ) is the source UV spectrum, A(λ) is the erythemal action spectrum (CIE, 1987) and the integration is over the UV wavelengths. The erythemal irradiances and the UVA irradiances were measured with a radiometer (model 3D V2.0, Solar Light Co., Philadelphia, USA) fitted with an erythemal sensor and a UVA sensor. Both the erythemal sensor and the UVA sensor were calibrated against a calibrated dual holographic grating spectroradiometer with calibration traceable to the National Measurement Laboratory (Wong et al., 1995). Additionally, for each measurement of the erythemal and UVA irradiances, the visible irradiances were measured with a LUX meter (model EMTEK LX-102, supplier, Walsh's Co., Brisbane, Australia). The ambient erythemal UV irradiances in full sun on a horizontal plane were continuously monitored during daylight hours through the summer with a Biometer (model 501, Solar Light Co., Philadelphia, USA) permanently mounted on an unobstructed building roof. The Biometer was calibrated against the calibrated spectroradiometer.

The irradiance measurements were at ground level on a horizontal plane over a Southern Hemisphere summer in the tree shade on the side of the trunk furthermost from the sun between 1 December 1998 and 28 February 1999. The trees employed in the research were forty-two isolated trees in the grounds of the University of Southern Queensland campus, Toowoomba, Australia at a latitude of 27.5^{o} S and altitude of 693 m above sea level. The trees were evergreen Australian trees and mainly a range of gum trees. The width of the tree canopies ranged from 2.2 to 13 m, the tree heights ranged from 6.4 to 25 m and the height above the ground to the first branches ranged from 0.4 to 10 m. The cloud cover varied between zero cloud and seven eights of the sky dome covered in cloud as determined by an observer. The cloud cover and atmospheric conditions vary with time and from day to day. The measurements over the summer were designed to take into account the typical cloud and other atmospheric conditions that would be encountered over a Southern Hemisphere summer.

2.2 Diffuse Irradiances

The diffuse UV_{ery} and UVA irradiances were measured by holding a shadow band approximately 15 cm above the respective detector to shadow it. The irradiances were measured approximately in the centre of the visible tree shade for the relevant tree. No measurements were made if there was no shade visible due to cloud cover. The diffuse UV radiation in both wavebands was also measured in full sunlight and at least 3 metres clear of any shade. These measurements were as close as possible in time to the measurements in the tree shade to minimise the effects of variations in solar zenith angle and atmospheric conditions.

The diffuse irradiances were measured for each of the trees between 8:30 Australian Eastern Standard Time (EST) and 9:30 EST, 11:30 EST and 12:30 EST and 14:30 EST and

15:30 EST. For the remainder of this paper, these time periods are referred to as morning, noon and afternoon.

3. RESULTS

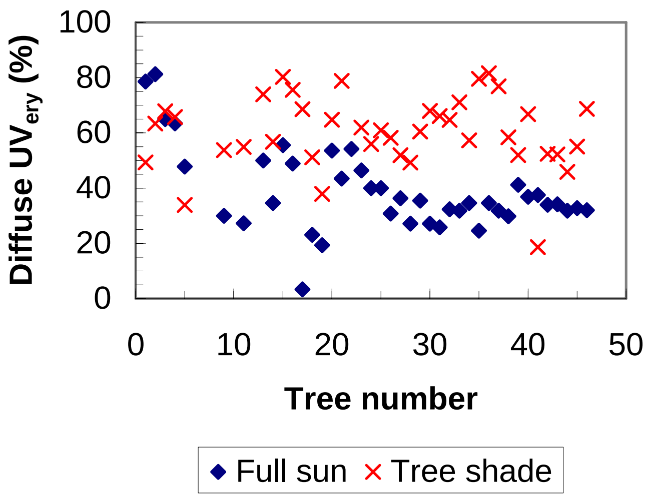
3.1 Diffuse UV

The diffuse erythemal UV irradiances as a percentage of the erythemal UV in the tree shade are presented in Figure 1 for the morning, noon and afternoon. In comparison, the diffuse erythemal UV irradiances as a percentage of the erythemal UV in full sun are also shown. The percentage diffuse UV_{ery} irradiances in tree shade range from 19% to 82%, 39% to 80% and 45% to 92% for the morning, noon and afternoon respectively. Figure 2 provides the percentage of the UVA in the tree shade at the three time periods. The variation in the percentages of diffuse UV in both the sun and the shade is most likely due to the variation in the amount of cloud cover from zero cloud to seven eights cloud over the summer of the measurements. In the shade, the additional contributing factor to the variation is any contribution that differences in canopy density between trees may make on the diffuse UV.

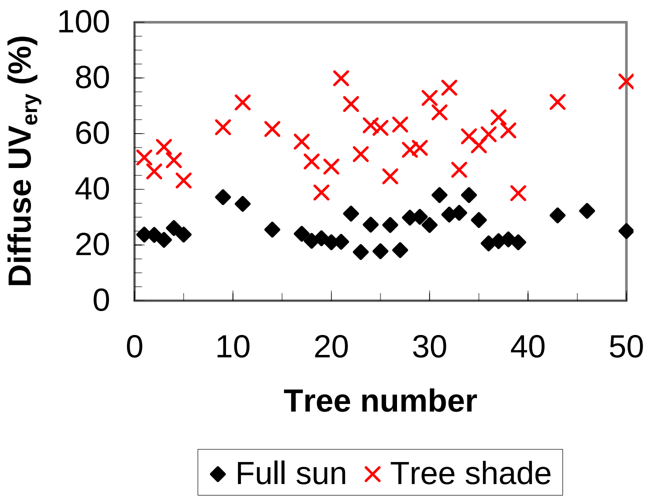
For the majority of the cases, the percentage diffuse UV_{ery} and UVA are higher in the tree shade compared to the respective diffuse irradiance percentages in the full sun. At noon, there is a better defined separation between the diffuse erythemal UV in the tree shade compared to the diffuse erythemal UV in the full sun. In comparison, for the morning and afternoon, the diffuse erythemal UV in the full sun is in general higher with less difference between the diffuse UV in the tree shade and the full sun. This is most likely due to the higher atmospheric pathlength in the morning and afternoon resulting in higher percentage diffuse UV in the full sun.

In Figure 1 there are two data points in the morning and one data point in the afternoon with more than 70% diffuse erythemal UV in full sun. Similarly, in Figure 2 there is one data point in the morning and one data point in the afternoon with more than 70% diffuse UVA in full sun. These high diffuse irradiances in full sun were most likely due to the seven eights cloud at the time on these specific days. The percentage diffuse UVA in Figure 2 is different to the percentage diffuse UV_{ery} in Figure 1, possibly due to the differences in Rayleigh scattering for the two wavebands.

(a)



(b)



(c)

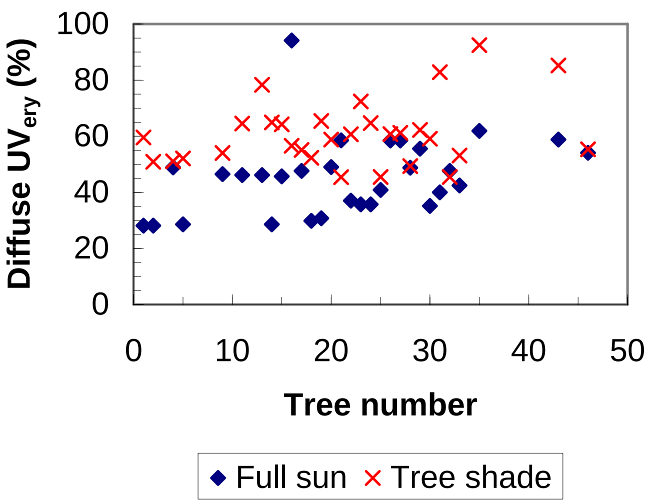
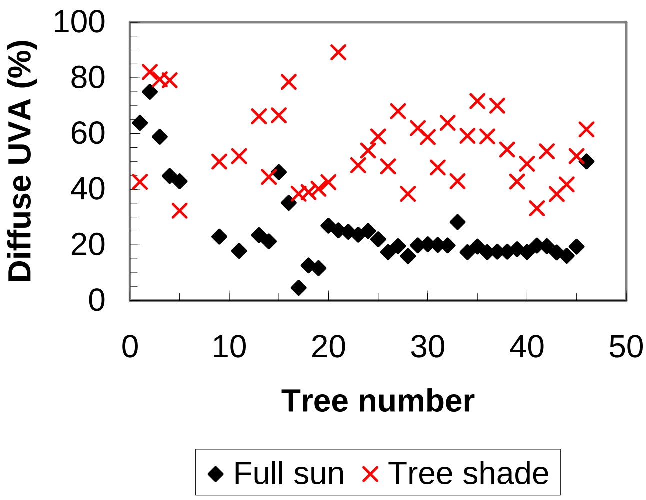


Figure 1 – The percentage diffuse erythemal radiation in the full sun and the tree shade in the (a) morning, (b) noon and (c) afternoon.

(a)



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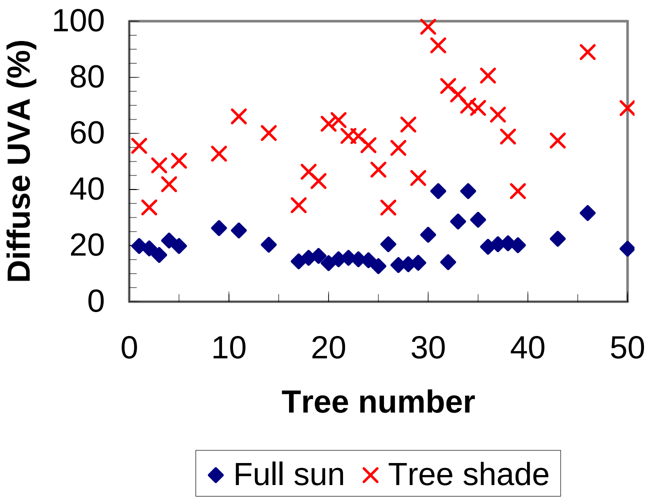

(c)

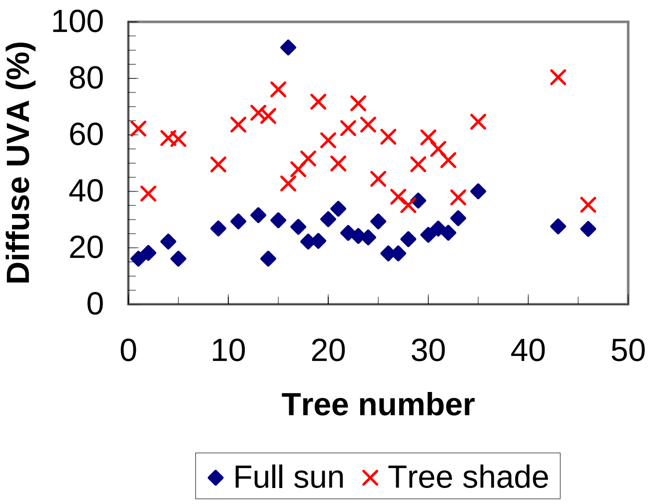

Figure 2 – The percentage diffuse UVA radiation in the full sun and the tree shade in the (a) morning, (b) noon and (c) afternoon.

3.2 Average Diffuse UV

The absolute diffuse UV_{ery} and UVA irradiances on a horizontal plane at ground level averaged over all of the trees in tree shade and in full sun are provided in Table 1 for the morning, noon and afternoon. The unit for the UV_{ery} irradiances is MED/h, where an MED (minimum erythemal dose) is the amount of biologically effective UV required to produce barely perceptible erythema after an interval of 8 to 24 hours following UV exposure (Diffey, 1992). The error is one standard deviation of the mean. The diffuse irradiances have been averaged over all of the trees measured over the summer to take into account the atmospheric conditions encountered over the summer. The diffuse irradiances in the tree shade may also be affected by the tree parameters such as canopy density. However, the aim of this paper is to provide a general guide for the trees employed in the project. The standard error in the diffuse UV radiation is less than 10%.

The diffuse UV_{ery} and UVA irradiances in the tree shade are higher at noon by 48% and 20% respectively compared to the average of the morning and afternoon irradiances, most likely due to the higher noon irradiances. Employing linear interpolation between the three measurement times provides an exposure due to the diffuse UV to a horizontal plane in tree shade of 4 MED and 14 J cm^{-2} between 9:00 EST and 15:00 EST for erythemal UV and UVA respectively. For comparison, the erythemal UV irradiances on a horizontal plane in full sun for a relatively cloud free day (4 December 1998) and a cloudy day (17 December 1998) are provided in Figure 3. The units are in MED/15 minutes as 15 minutes was the recording period of the datalogger on the Biometer. The erythemal irradiances summed between 9:00 EST and 15:00 EST are 29.1 MED and 25.4 MED for the cloud free and cloudy days respectively.

Table 1 – The diffuse UV_{ery} and UVA irradiances averaged over all of the trees in tree shade and in full sun.

Waveband	Diffuse UV Radiation					
	Tree Shade			Full Sun		
	morning	noon	afternoon	morning	noon	afternoon
UV_{ery} (MED/h)	0.56±0.02	0.80±0.06	0.52±0.03	0.70±0.03	0.90±0.03	0.77±0.04
UVA (mW cm^{-2})	0.61±0.03	0.72±0.06	0.59±0.03	0.73±0.04	0.82±0.03	0.77±0.03

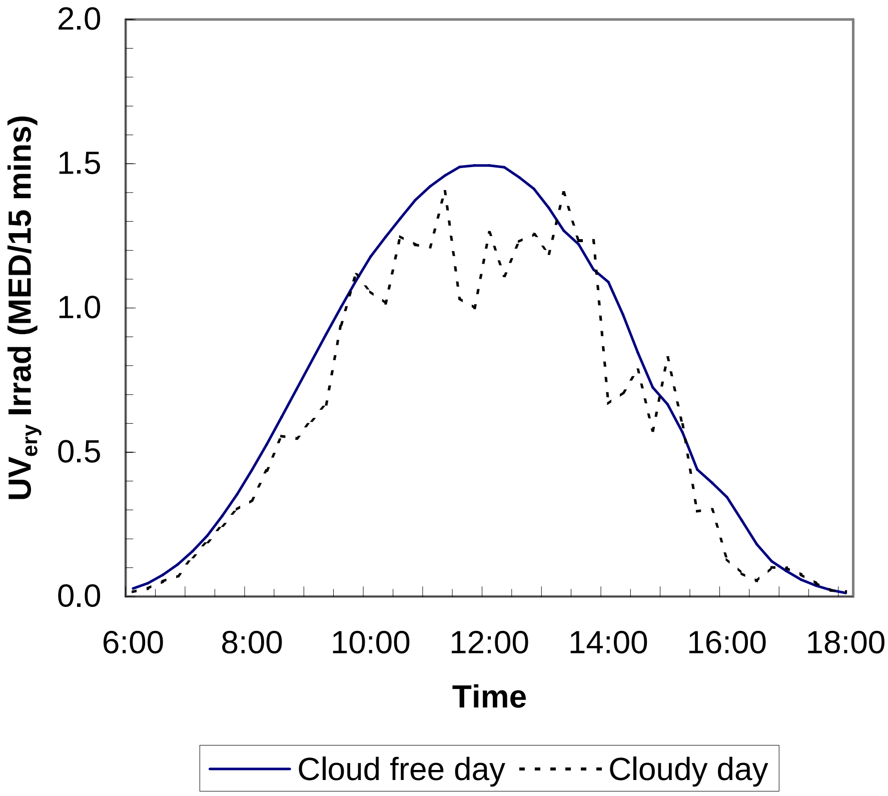

Figure 3 – Erythemal UV data for a relatively cloud free day and a cloudy day in summer.

The averages over all the trees of the percentage diffuse UV radiation in the tree shade compared to the UV in the tree shade and the percentage diffuse UV radiation in the full sun compared to the UV in full sun are provided in Table 2. Additionally, the percentage diffuse visible radiation in tree shade and full sun are provided for comparison. The error is one standard deviation of the mean.

For the summer measurements in this research, the percentage diffuse radiation of UV_{ery} in the tree shade is relatively constant at about 60% from the morning period to the afternoon period. In comparison, as expected due to the longer atmospheric pathlength causing additional scattering in the morning and afternoon, the percentage diffuse radiation in the full sun is higher in the morning and afternoon compared to that at noon. The differences between the visible waveband and the erythemal UV of the percentage diffuse radiation in the tree shade was approximately the same in the morning, noon and afternoon time periods. In comparison, the same difference in the full sun varies over the three periods.

Table 2 – Average over all the trees of the percentage diffuse UV and visible irradiances in tree shade and in full sun.

Waveband	Percentage Diffuse Radiation (%)					
	Tree Shade			Full Sun		
	morning	noon	afternoon	morning	noon	afternoon
UV_{ery}	60±2	60±2	61±2	39±2	26±1	46±3
UVA	54±2	57±3	56±2	26±2	20±1	28±2
Visible	53±3	54±3	54±4	21±4	14±1	19±3

DISCUSSION

Quantitative measurements and research on UV radiation in different environments and settings is vital in developing and assessing UV preventative strategies for the reduction of skin cancer and other UV related problems for humans. This paper has provided the first set of quantitative data of diffuse erythemal UV and UVA in tree shade at a sub-tropical Southern Hemisphere latitude. Over the summer, approximately 60% of the erythemal UV radiation in the tree shade is due to the diffuse component. Similarly, approximately 56% of the UVA radiation in the tree shade is due to the diffuse component. The standard error in the set of measurements is less than 10%. These values approach the percentage diffuse UV component in full sun for winter. However, in the tree shade they are relatively constant from the morning to noon to afternoon periods. In comparison, there is a decrease in the percentage diffuse UV in full sun at noon compared to the morning and afternoon. For the erythemal UV, the decrease is from approximately 40% in the morning and afternoon to 26% at noon. The tree shade has increased the diffuse component in summer from 26% to 60% at noon and from approximately 40% in the morning and afternoon to 60%.

This high percentage of diffuse radiation has a consequence that the UV protective capability of hats for the relatively high UV irradiances in tree shade (Parisi et al., 1999, Parsons et al., 1998), while useful, is not as high as in full sun. The exposures to diffuse UV on a horizontal plane in the tree shade between 9:00 EST to 15:00 EST were of the order of 4 MED and 14 J cm^{-2} for erythemal UV and UVA respectively. This high diffuse UV component in the shade may result in high UV exposures to not only parts of the body on a horizontal plane that are not protected, but also, equally high UV irradiances to parts of the body, including the eyes and face, that are not UV protected.

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