COMPARISON BETWEEN SEASONS OF THE ULTRAVIOLET ENVIRONMENT IN THE SHADE OF TREES IN AUSTRALIA

A.V. Parisi[1,*], J.C.F. Wong[2], M.G. Kimlin[1], D. Turnbull[1], R. Lester[1]

[1]Centre for Astronomy and Atmospheric Research, Faculty of Sciences, University of Southern Queensland, TOOWOOMBA 4350 AUSTRALIA. Fax: 61 74 6312721.

[2]Centre for Medical and Health Physics, Queensland University of Technology, GPO Box 2434, BRISBANE 4001 AUSTRALIA.

[*]To whom correspondence should be addressed

Abstract

Background/Purpose: *This paper has considered the erythemal UV (UV_{ery}), UVA and visible irradiances in the shade of Australian trees for each season at a sub-tropical southern hemisphere site.*

Methods: *The irradiances in tree shade have been measured with radiometers as a percentage of the irradiances in the sun for each season of the year.*

Results: *Although the solar irradiances are lower in winter, the percentages of the UV in tree shade compared to the UV in full sun are marginally higher (by up to 7%) in the winter compared to summer. The range of percentages for UV_{ery} was up to double that of the percentages of the visible waveband. The percentages for UV_{ery} were also higher than for the UVA waveband. The percentages of the irradiances in the tree shade compared to full sun are lower at noon by an amount of 8% to 14% compared to the morning and afternoon for the UV_{ery} waveband. The ratio of UVA to UV_{ery} is lower in the tree shade compared to the full sun.*

Conclusion: *The UVA to UV_{ery} ratio is expected to be even lower in the tree shade as a result of ozone depletion. This combined with the visible irradiances in the tree shade not being a reliable indication of the biologically damaging UV irradiances has consequences for public health and skin cancer prevention.*

Keywords: *erythema; ultraviolet; shade; tree; UVA*

INTRODUCTION

The solar ultraviolet (UV) irradiances at the surface of the Earth are influenced by season, time of day, latitude, atmospheric ozone, clouds and aerosols. The variation with season has been measured with both spectroradiometers and broadband meters in both the southern hemisphere (for example, 1-4) and northern hemisphere (for example, 5, 6). These variations have been measured in open sunlight.

For certain times of the year, the UV irradiances in tree shade have been studied (7-9), along with the UV spectrum in tree shade (10) and the diffuse UV in tree shade during summer (11). Additionally, the UV irradiances in open tree canopies have been modeled (12). To the authors' knowledge, no previous research has investigated the variation of the solar UV irradiances with season on a horizontal plane in tree shade. In this research, the comparison between seasons of the UV in the shade of single Australian trees at a sub-tropical southern hemisphere site has been investigated.

MATERIALS AND METHODS

Summer and Winter UV Spectrum

The solar UV spectrum was measured at 1 nm increments in summer and winter with a UV spectroradiometer with wavelength calibration to the mercury UV spectral lines and absolute irradiance calibration traceable to the national UV standard lamp (13). The spectrum was measured in full sun on a horizontal plane in an open field in Toowoomba, Australia (latitude 27.5 ^{o}S and 693 m above sea level). In summer, the UV spectrum was measured at approximately 11:00 EST (Australian Eastern Standard Time) for a solar zenith angle of 12 ^{o} with the solar disc clear of cloud cover. Similarly, in winter, the UV spectrum was measured at approximately 11:00 EST for a solar zenith angle of 47 ^{o}. The two solar spectra were weighted at each nanometre with the erythemal action spectrum, (14) to provide the typical spectral erythemal UV irradiances in summer and winter.

Shade Description

The trees employed in this research have been described elsewhere (15). They were evergreen Australian trees in Toowoomba in the grounds of the University of Southern Queensland and mainly consisted of a range of gum trees. The tree canopy size ranged in width from 2.2 to 13 m and in height from 6.4 to 25 m and the height above the ground to the first branches ranged from 0.4 to 10 m. The tree canopy transmission in the visible waveband ranged from 45% to 94%.

Shade UV Measurements

The UV irradiances were measured in the tree shade with a radiometer (model 3D V2.0, Solar Light Co., Philadelphia, PA, USA) fitted with a UVA (320-400 nm) detector and an erythemal UV (UV_{ery}) detector. The UVA detector has a peak response at 355 to 365 nm and the response has dropped to 50% of the peak response at 327 nm and 382 nm. The UV_{ery} detector is sensitive to wavelengths shorter than 385 nm with a response that approximates the erythemal action spectrum (14). Each detector was calibrated against the calibrated spectroradiometer with the solar UV as the source, in each of the four seasons. This consisted of measuring the respective irradiances with each of the detectors concurrently with spectroradiometer scans up to 400 nm between 8.00 Australian Eastern Standard Time (EST) and noon.

The visible irradiances were measured with a LUX meter (model EMTEK LX-102, supplier, Walsh's Co., Brisbane, Australia). In each of the four seasons of the year, the UV_{ery}, UVA and visible irradiances were measured for 36 to 50 trees. The measurements were spread across each of the months in the respective season. Each of the irradiances were measured for each of the trees between 8.30 EST and 9.30 EST, 11.30 EST and 12.30 EST and 14.30 and 15.30 EST. For the remainder of the paper, these periods are referred to as 9.00 EST, noon and 15.00 EST. The cloud cover on the measurement days as determined by an observer varied between zero cloud and seven eighths of the sky dome covered in cloud. No measurements were undertaken on the days with eight eighths of cloud when there was no discernible visible tree shade.

The UV_{ery}, UVA and visible irradiances were measured at approximately ground level on a horizontal plane at each of the three periods for each of the trees in each of the seasons by: measurement of the irradiances in the full sun immediately before and after the measurements in the shade and at least 2 metres from any shade; and measuring each of the three irradiances on a grid of 1 to 2 metres inside the visible shade of each tree.

RESULTS

Summer and Winter UV Spectrum

Two typical UV spectra in full sun are provided in Figure 1 for a relatively cloud free day in each of summer and winter. Additionally, the Figure provides the corresponding spectral erythemally weighted irradiances. The spectral irradiances are higher and shifted to shorter wavelengths for the summer spectrum. This has an effect on the erythemal UV irradiances as shown in the second part of the Figure.

Shade UV Measurements

The distribution of the UV_{ery}, UVA and visible irradiances in the shade of a typical tree at 9.00 EST are shown in Figure 2 for summer and for the same tree in winter. The amount of cloud cover was seven eighths and zero eighths in summer and winter respectively for these two days. Additionally, the average for each set of tree measurements of the irradiances in the full sun are provided in the Figure. The unit of MED (minimum erythema dose) is defined as 200 J m^{-2} (16). For the winter, the averages for this tree are 0.25 MED h^{-1}, 0.85 mW cm^{-2} and 15300 LUX and for summer the averages are 1.4 MED h^{-1}, 2.0 mW cm^{-2} and 37200 LUX. In this latter case, the irradiances are affected by the cloud cover. The change in distributions from summer to winter is expected due to the change in the solar zenith angle of the sun. For this tree and this time of the day, the relative change from summer to winter is higher for the UV_{ery}, compared to the UVA and visible irradiances. Specifically, for both the shade and full sun, in Figure 2, the irradiances drop by factors of approximately 5.4 to 5.6 (Figure 2 a/d), 1.6 to 2.3 (Figure 2 b/e) and 1.5 to 2.4 (Figure 2 c/f) for the UV_{ery}, UVA and visible irradiances respectively.

The larger relative drop for the UV_{ery} is expected by considering Figure 1 where the UV_{ery} irradiances in winter are both reduced in irradiance and also the short wavelength cut-off shifts to longer wavelengths.

The UV_{ery} irradiances at each of the grid points in the tree shade have been averaged for each of the trees and plotted for the 9.00 EST, noon and 15.00 EST periods for summer and winter in Figure 3. This Figure shows the natural variability of the UV irradiances in the tree shade for the three different periods of the day in summer and winter. In general, the differences between the UV_{ery} irradiances in the full sun and the tree shade are largest for both the summer and winter at noon due to the higher percentage of diffuse erythemal UV in the morning and afternoon (11). For the noon period, in summer the range of irradiances are 1.8 to 3.8 MED h^{-1} and 0.5 to 1.9 MED h^{-1} for the full sun and tree shade respectively. In comparison, the ranges of irradiances are 0.8 to 1.2 MED h^{-1} and 0.3 to 0.7 MED h^{-1} in winter for the same time period.

Seasonal Averages

The winter and summer averages of the erythemal UV and UVA irradiances in the sun and the tree shade are provided in Figure 4 for each of the 9.00 EST, noon and 15.00 EST periods. It is worth noting that the averages for the seasons are calculated using the days on which measurements were made. The average over all the days in the season may be different, however, the results do show the differences between shade and full sun. For all three periods, the differences between the winter and summer irradiances are less in the tree shade compared to those in the sun.

The irradiances expressed as percentages of the respective irradiances in full sun have been averaged for each period of the four seasons and are provided in Table 1. The error is a standard error in the mean (SEM). Over the whole year, the ranges are 19 to 33%, 40 to 56% and 32 to 52% for the visible, UV_{ery} and UVA wavebands respectively. For the noon period the average of the UV_{ery} percentages for summer is higher by a factor of 1.8 compared to the same percentage for the visible. This is due to the higher amount of Rayleigh scattering at the shorter wavelengths of the UV_{ery}.

DISCUSSION

This paper has considered the erythemal UV, UVA and visible irradiances in the shade of Australian trees at a sub-tropical southern hemisphere site for each season. The variation may be different in full forest canopies compared to a single tree canopy. Further research is required for full forest canopies and for different species of trees. The measurements were made from summer 1998 to spring 1999. It is worth noting that this was during a La Nina cycle on the east Australian coast with above average amounts of cloud cover.

Previous research has considered the UV in tree shade for particular periods of the year (9). This paper has extended that research to provide for each season of the year, the UV in tree shade as a percentage of the irradiances in the sun. Although the solar irradiances are lower in winter, the percentages of the UV in tree shade compared to the UV in full sun are marginally higher (by up to 7%) in the winter compared to summer. It is worth noting the consistency in the ratios for each waveband. The range of percentages for UV_{ery} was up to double that of the percentages of the visible waveband. The percentages for UV_{ery} were also higher than for the UVA waveband. This is consistent with the higher shade ratio in the UVB waveband than in the UVA waveband (10). The scattering in a leaf canopy is greater in the photosynthetically active radiation or visible waveband (17) compared to the UVA or UVB wavebands. Consequently, the differences in the ratios between the wavebands are not due to differences in the scattering in the tree canopies. Rather, they are predominantly due to the differences in the Rayleigh scattering for each waveband in the atmosphere. These differences in the scattering of the wavebands explains why the seasonal averages (Figure 4) of the UVA in winter in full sun is higher than the UVA in tree shade in summer, compared to the opposite for the UV_{ery} with the irradiances in the summer tree shade higher than those in the winter in the sun.

The percentages of the irradiances in the tree shade compared to full sun are lower at noon by an amount of 8% to 14% compared to the morning and afternoon for the UV_{ery} waveband. The differences between the noon and morning and afternoon percentages are larger for the UV_{ery} compared to the visible for each of the respective seasons. This is due to the larger atmospheric pathlength in the morning and afternoon contributing to a greater degree of Rayleigh scattering.

The ratio of UVA to UV_{ery} ranges from 1.2 to 1.7 and 2.7 to 4.1 for summer and winter respectively in the full sun. The same ratio ranges from 1.0 to 1.2 and 2.0 to 3.5 for summer and winter respectively in the tree shade. For both the tree shade and the full sun, the ratio is lower in the summer. This is due to the shift to shorter wavelengths of the UV spectrum in summer (Figure 1). In the tree shade, the ratio is also lower than in the full sun in both seasons. This is due to the higher UV protection provided by the tree shade in the UVA waveband compared to the UVB due to the higher degree of diffuse UVB radiation compared to the UVA waveband. This is due to more Rayleigh scattering in the atmosphere at the shorter waveband. Ozone depletion will result in a higher proportion of the shorter UVB wavelengths reaching the earth (18). Consequently, the UVA to UV_{ery} ratio is expected to be even lower in the tree shade as a result of ozone depletion. This combined with the visible irradiances in the tree shade not being a reliable indication of the biologically damaging UV irradiances has consequences for public health and skin cancer prevention. Public health campaigns incorporating quantitative information on the UV irradiances in tree shade, such as provided in this paper, are required. Specifically, tree shade protects and reduces exposure to environmental UV_{ery}, however, it is not total protection and additional UV protective strategies are required if prolonged periods in the tree shade are anticipated.

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Table 1 - The irradiances in the tree shade (mean±SEM) as a percentage of the respective irradiances in the full sun.

Waveband	Time period	summer	autumn	Winter	spring
Visible	9.00 EST	30 ± 4	20 ± 2	26 ± 1	29 ± 1
	Noon	22 ± 3	21 ± 1	19 ± 1	21 ± 2
	15.00 EST	24 ± 2	24 ± 2	26 ± 1	33 ± 2
UV_{ery}	9.00 EST	53 ± 3	55 ± 2	56 ± 1	51 ± 2
	Noon	40 ± 3	41 ± 2	47 ± 1	41 ± 2
	15.00 EST	50 ± 2	55 ± 2	55 ± 1	55 ± 1
UVA	9.00 EST	39 ± 3	39 ± 2	49 ± 3	42 ± 2
	Noon	32 ± 3	33 ± 2	34 ± 1	40 ± 6
	15.00 EST	36 ± 2	41 ± 1	44 ±1	52 ± 7

FIGURE CAPTIONS

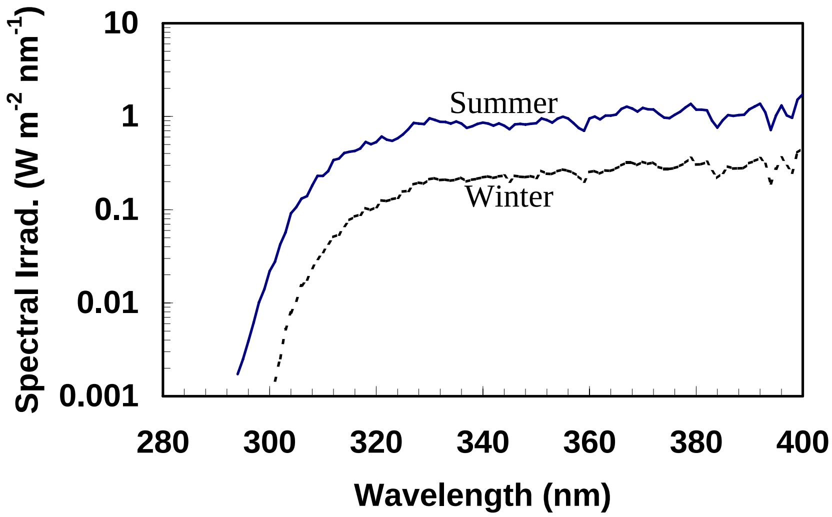
Figure 1 - (a) Typical solar UV spectral irradiance for a relatively cloud free period in winter and summer and (b) the respective erythemal UV spectral irradiances.

Figure 2 - The distribution of the irradiances in the shade of a tree at 9.00 EST for (a) UV_{ery}, summer, (b) UVA, summer, (c) visible, summer, (d) UV_{ery}, winter, (e) UVA, winter and (f) visible, winter. The units are MED h^{-1}, mW cm^{-2} and 100 LUX respectively for the UV_{ery}, UVA and visible irradiances. The X represents the tree trunk and the values in bold are the irradiances in full sun.

Figure 3 - The UV_{ery} irradiances in the tree shade (◊) and the corresponding full sun (■) in summer for (a) 9.00 EST, (b) noon and (c) 15.00 EST and in winter for (d) 9.00 EST, (e) noon and (f) 15.00 EST.

Figure 4 - Variations between the 9.00 EST, noon and 15.00 EST periods of the irradiances for the summer and winter in the sun and the shade for (a) erythemal UV and (b) UVA.

(a)



(b)

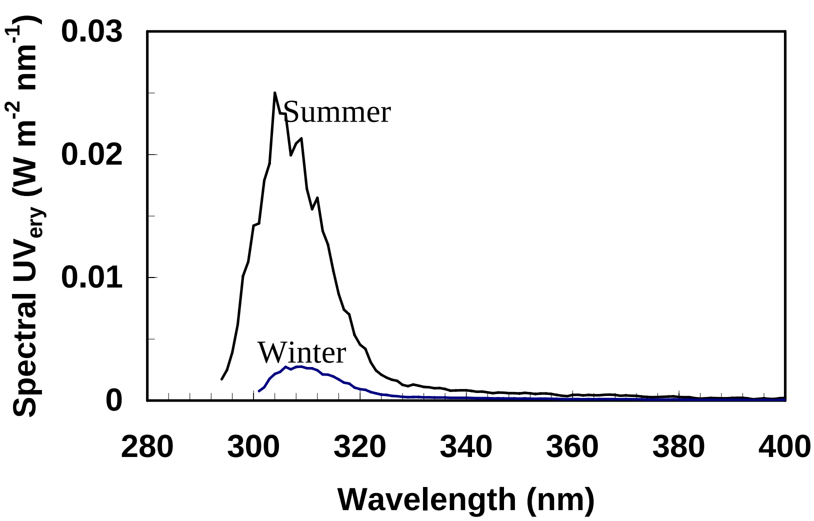


Figure 1 - (a) Typical solar UV spectral irradiance for a relatively cloud free period in winter and summer and (b) the respective erythemal UV spectral irradiances.

(a)

	1.0	1.3	1.2	1.4	X	
	1.4	1.2	1.0	1.1	1.1	1.3
	1.2	1.1	1.0	1.0	1.1	1.4
1.5	1.3	1.2	1.3	1.2	1.3	1.4
	2.4	1.7	1.5	1.9		
	1.5	2.0	2.1			

2.7

(b)

	1.2	2.2	1.5	1.8	X	
	2.8	2.9	2.4	1.7	1.4	2.6
	1.7	2.6	1.7	1.4	1.5	2.3
2.2	1.5	1.6	1.4	1.4	1.5	1.6
	2.3	1.7	1.9	2.4		
	2.3	2.5	2.6			

3.2

(c)

	610	480	320	320	X	
	710	450	530	260	180	360
	210	510	250	130	190	340
280	420	320	690	250	500	490
	230	210	330	350		
	420	310	500			

860

(d)

			X		
		0.2			
	0.2		0.2		
	0.2	0.2	0.2	0.2	
0.2		0.2		0.3	0.3
0.3		0.2	0.3	0.2	
0.3		0.3	0.2	0.2	
0.4				0.2	
0.4		0.3	0.2		
	0.3	0.3	0.2		
		0.3			

0.5

(e)

			X		
		0.6			
	0.6		0.6		
	0.7	0.7	0.6	0.6	
0.7		0.6		1.3	0.8
0.8		0.7	1.5	0.6	
1.4		1.2	0.6	0.6	
1.3				0.5	
1.5		0.9	0.6		
	0.7	0.9	0.6		
		1.5			

2.0

(f)

			X		
		70			
	80		120		
	100	60	150	60	
70		65		250	120
150		100	450	70	
300		220	70	65	
130				120	
350		80	250		
	150	170	150		
		300			

595

Figure 2 – The distribution of the irradiances in the shade of a tree at 9.00 EST for (a) UV_{ery}, summer, (b) UVA, summer, (c) visible, summer, (d) UV_{ery}, winter, (e) UVA, winter and (f) visible, winter. The units are MED h^{-1}, mW cm^{-2} and 100 LUX respectively for the UV_{ery}, UVA and visible irradiances. The X represents the tree trunk and the values in bold are the irradiances in full sun.

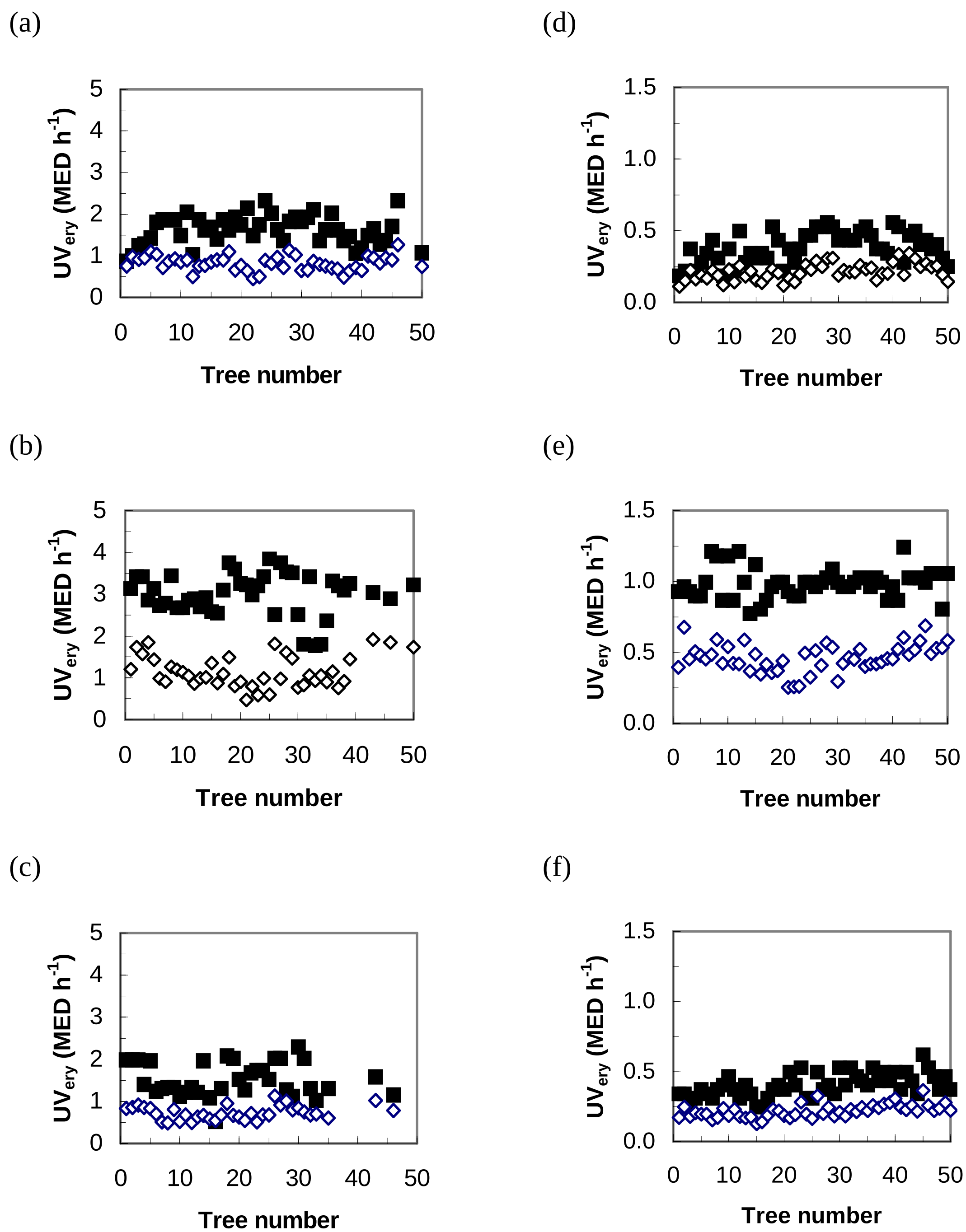
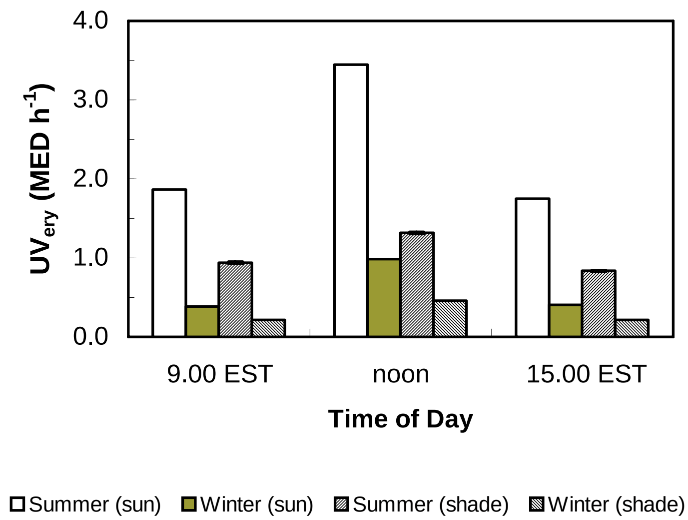


Figure 3 – The UV_{ery} irradiances in the tree shade (◊) and the corresponding full sun (■) in summer for (a) 9.00 EST, (b) noon and (c) 15.00 EST and in winter for (d) 9.00 EST, (e) noon and (f) 15.00 EST.

(a)



(b)

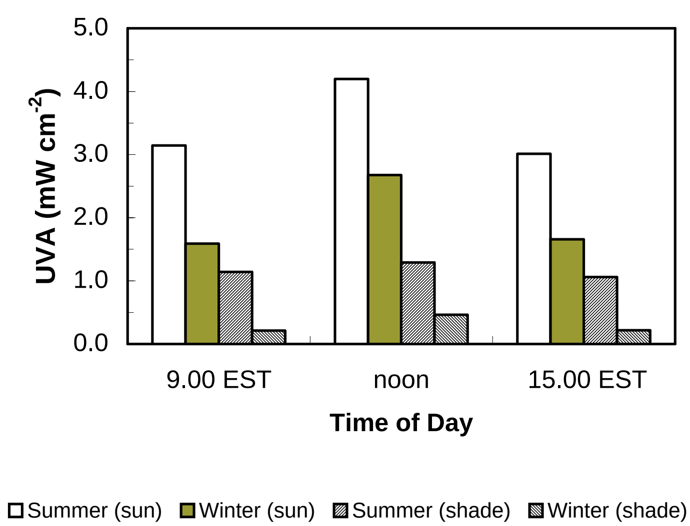


Figure 4 – Variations between the 9.00 EST, noon and 15.00 EST periods of the irradiances for the summer and winter in the sun and the shade for (a) erythemal UV and (b) UVA.