# THE ERYTHEMAL ULTRAVIOLET EXPOSURE FOR HUMANS IN GREENHOUSES

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**Running Title:** Erythemal UV in Greenhouses

### *Abstract*

A spectrum evaluator has been employed to evaluate the erythemal exposure in late spring and late summer at three sites and five orientations at each site inside a glass greenhouse with black shadecloth over the glass roof. The maximum in the erythemal irradiance in the greenhouse is not necessarily at noon. Over a day, the maximum erythemal exposure occurred on the eastern side of the greenhouse in the morning and on the western side in the afternoon. The erythemal irradiance on the eastern side in the morning was higher by 26% and 50% for horizontal and vertical surfaces respectively compared to the same site at noon. On the western side the irradiance was higher by 45% and 78% for the horizontal and vertical surfaces respectively compared to the same site at noon. The erythemal irradiance inside the greenhouse does not vary as much during the day as it does outside, for example, for horizontal surfaces, the ratio of the erythemal irradiance outside to the average inside the greenhouse varies from 66 to 112 to 74 for the morning, noon and afternoon periods respectively. Over a six hour period, the erythemal exposure to the shoulder for a standing posture in the greenhouse was 5 mJ $cm^{-2}$.

## 1. INTRODUCTION

Within a glass greenhouse, the UVA (320 to 400 nm) and the visible wavebands (400 to 700 nm) of solar radiation are present with no significant UVB (280 to 320 nm) due to the filtering properties of the glass (Parisi and Wong, 1997). The irradiances of these wavebands are lower than those present outside the greenhouse, particularly, within greenhouses with their glass roof covered by shadecloth. The UVA waveband affects humans with the tail of the erythemal action spectrum extending into the UVA waveband (CIE, 1987). The relative contribution of the solar UVA waveband to erythema becomes more significant when the UVB waveband is filtered, for example by glass (Parisi and Wong, 1997). Previous research has shown that repetitive suberythemal exposures produce a damaging effect on human skin (Anders et al., 1995, Lavker et al., 1995a, 1995b). Much of the skin damage induced by UVB wavelengths may also be induced by UVA (Urbach, 1993). Persons working continuous, long hours in a greenhouse may receive substantial cumulative exposure of erythemal UV radiation. No data on human exposure in a greenhouse is available for analysis of the health hazards.

Polysulphone dosimeters that are employed for measuring erythemally effective UV respond predominantly to UVB wavelengths (CIE, 1992) and as a result cannot be employed to measure the biologically effective UVA in a glasshouse. Similarly, the response of the Robertson Berger meter that is commonly used for measuring erythemal irradiances does not extend significantly into the UVA waveband (DeLuisi *et al*., 1992). A calibrated spectroradiometer may be utilised to measure the UVA spectral irradiance (Wong *et al*., 1995), however the equipment is expensive and impractical for the measurement of personal erythemal exposure at multiple sites simultaneously over the object of study.

A UV spectrum evaluator with an overall size of 3 cm x 3 cm based on four different dosimeter materials (Parisi *et al*., 1997) has been tested for measuring the erythemal exposure resulting from the UVA waveband of an artificial light source (Wong and Parisi, 1996). The method has been tested in measuring the erythemal exposure due to the solar UVA waveband in a small glass enclosure designed to simulate a large scale construction (Parisi and Wong, 1997). The purpose of this current research is to utilise the method with spectrum evaluators to determine the distribution of the erythemal UV in a glass greenhouse and the time variation of these irradiances in order to determine factors which could affect the distribution.

## 2. MATERIALS AND METHODS

*Ambient UVA Distribution*

The spatial variation of the UVA irradiances on a horizontal plane in the greenhouse at the University of Southern Queensland, Toowoomba, Australia (27.5$^{o}$ S latitude) was investigated with a UVA detector (Model 3D V2.0, Solar Light Co., Philadelphia, USA) in spring for three times of the day, namely, 9:00 Eastern Standard Time (EST), noon and 15:00 EST at the sites marked (x) in Figure 1. The measurements were taken at points that were not shaded by any plants or structural members of the greenhouse. The greenhouse is orientated with the longer sides facing the east and west direction as shown in Figure 1. The roof and sides of the greenhouse are glass with the glass on the roof also covered with mesh and black shade cloth. The solar spectrum and the solar spectrum filtered firstly by a piece of greenhouse glass and secondly by a piece of the greenhouse shadecloth was measured on 10 July at approximately 10:55 EST with a spectroradiometer described elsewhere (Parisi and Wong, 1997).

*Erythemal UV*

The technique of a spectrum evaluator consisting of four different dosimeter materials was employed to evaluate the erythemal UV (Parisi and Wong, 1996, Parisi *et al.*, 1997). The spectrum evaluators were exposed in the greenhouse in late spring on 12 November 1996 between 10:53 and 11:53 EST (average solar zenith angle $18.8^{o}$) at the site, WS (Figure 1) approximately half way along the length of the western side. A spectrum evaluator was employed at each of the five orientations provided in Table 1 with one on a horizontal plane (T) and the other four in a vertical plane and orientated to each of the north (N), east (E), south (S) and west (W) directions. The cloud cover recorded by the Bureau of Meteorology observer was 1 okta at 9:00 EST and 6 okta at 15:00 EST. The exposure period of one hour was required to produce a reasonable change in the optical absorbance of the dosimeter material. These measurements were repeated on 28 November 1996 and 5 February 1997 at the sites ES, C and WS shown in Figure 1. Details of the exposure times, cloud cover and solar zenith angles are given in Table 2.

A polynomial function with a cutoff at 330 nm was employed to evaluate the UV spectrum employing the method previously developed (Parisi *et al.*, 1997). The biologically effective UV for humans, $UVBE_{ery}$, was calculated employing the action spectrum for erythema (CIE, 1987). The ambient erythemal UV and the UVA irradiances on a horizontal plane were measured outside the glasshouse during the exposure period with the Solar Light radiometer mentioned previously. This was fitted with a UVA and an erythemal sensor. The visible illumination was measured with a LUX meter (EMTEK LX-102, supplier, Walsh & Co., Queensland, Australia).

## 3. RESULTS

*Ambient UVA Distribution*

The ambient UVA irradiances on a horizontal plane at the greenhouse sites (Figure 1) at 9:00, 12:00 and 15:00 EST are presented in Table 3. At each time, all the central sites have similar irradiances as do the three eastern sites and the three western sites, thus allowing evaluation of the erythemal UV to be carried out at three representative sites (ES, C, WS) as shown in Figure 1. The unfiltered and the shadecloth filtered and the glass filtered solar spectral irradiances are provided in Figure 2. The glass transmits negligible UVB and the shadecloth transmits approximately 30% of the UVA and UVB component.

*Erythemal UV*

The $UVBE_{ery}$ and total UVA irradiances on 12 November for the five orientations calculated employing the spectra evaluated with the spectrum evaluator are provided in Table 1. The irradiances represent the average over the one hour exposure period and take into account any shading by structural elements and plants throughout the period. The erythemal and UVA irradiances on the horizontal plane (T) are higher due to the small zenith angle of the sun. The irradiances on the north, east and south facing vertical sides were predominantly the same with a higher irradiance on the western facing side due to the proximity to the western side of the greenhouse. For the erythemal irradiance on the horizontal plane, an exposure period of approximately 24 hours is required to provide a 1 MED exposure where an MED is defined as

20 mJ $cm^{-2}$ (Diffey, 1992) and is the amount of biologically effective UV required to produce barely perceptible erythema after an interval of 24 hrs following exposure in people of skin type 1.

The irradiances measured with the radiometers outside the glasshouse on 12 November, 1996 are provided in Table 4. The erythemal detector is not sensitive enough to measure the erythemal irradiance inside the glasshouse. There is no irradiance in the UVB waveband due to the filtering properties of the glass. Due to the changing cloud cover, the amount of visible radiation outside is higher at 11:45 EST compared to 10:45 EST. Over the period, the visible illumination increases more than the UVA irradiance with the ratio of visible to UVA rising from $1.7x10^4$ to $2.2x10^4$.

Table 5 provides the evaluated $UVBE_{ery}$ irradiance for each of the orientations (T, N, E, S, W) at the ES, C and WS sites for the morning, noon and afternoon periods on 28 November, 1996. The maximum $UVBE_{ery}$ in the greenhouse does not necessarily occur at noon. The zenith angle of the sun in the morning and afternoon means that the irradiance is predominantly through the side of the greenhouse. As shown in Figure 3, this results in a higher irradiance in the morning to the ES site for the horizontal surface and in the afternoon to the WS site for the horizontal surface. The erythemal irradiance at the ES site in the morning is higher by 26% compared to the noon irradiance at the same site with the erythemal irradiance in the afternoon at the WS site being 45% higher compared to that at the same location at noon.

The change with time of day of the average of the erythemal irradiances to the four vertical surfaces of the four orientations (N, E, S, W) are provided in the second half of

Figure 3. The average to the vertical surfaces at the ES site is higher by 50% in the morning compared to the irradiance at the same site at noon and that to the vertical surfaces at the WS site in the afternoon is higher by 78% compared to that at the same site at noon. Throughout the day, the erythemal irradiance for humans varies much more at the ES and WS sites compared to the C site which remains relatively uniform. The effect of the increased cloud in the afternoon (5 okta) compared to the morning (0 okta) is minimal on the average irradiance to the vertical surfaces at the C site.

The erythemal irradiances in the greenhouse on 5 February, 1997 are provided in Table 6 for the morning, noon and afternoon periods at the ES, C and WS sites. The irradiances are to a horizontal plane and the column labelled as vertical represents the average of the irradiances to the vertical surfaces orientated to the north, east, south and west. The UVA and erythemal irradiances and the visible illumination measured on a horizontal plane outside the greenhouse for the 28 November 1996 and 5 February 1997 are provided in Table 7. The columns labelled am, noon and pm represent the average of the values measured at the start and end of the periods 09:00 to 10:00, 11:30 to 12:30 and 14:00 to 15:00 respectively.

The ratio of the erythemal irradiance measured outside the greenhouse on a horizontal plane to the average of the erythemal irradiances measured in the greenhouse at the ES, C and WS sites on a horizontal plane changes throughout the day. For the 28 November, 1996, these vary from 66 to 93 to 46 for the morning, noon and afternoon periods respectively. On the 5 February, 1997, these vary from 66 to 112 to 74 for the morning, noon and afternoon periods respectively. Similarly, the ratio of the erythemal irradiance measured on a horizontal plane outside to the average of that measured to the four vertical orientations at all sites varies from 133 to 240 to 89 and from 116 to 269 to 135 for the 28 November and 5 February respectively. These results show that the erythemal UV of the solar irradiance does not vary as much during the day inside the greenhouse as it does outside.

*Six Hour Exposures*

Interpolation of the erythemal irradiances between the three measurement periods in the morning, noon and afternoon provides a total exposure to a horizontal plane for the six hour period of 5 mJ $cm^{-2}$ for $UVBE_{ery}$ on 28 November, 1996. This is the average of the exposures to the ES, C and WS sites. On 5 February, the six hour exposure is 5 mJ $cm^{-2}$ for $UVBE_{ery}$. Workers in a greenhouse would receive an exposure of 1 MED in approximately four days. A noteworthy point is that even though the erythemal irradiance outside the greenhouse was higher on 5 February compared to 28 November, the $UVBE_{ery}$ inside the greenhouse over the six hour period was relatively constant.

Over the six hour period, the exposures to the vertical surfaces were a maximum for the eastern orientation at the ES site and for the western orientation at the WS site. These averaged to 3.0 mJ $cm^{-2}$ of $UVBE_{ery}$ exposure for the 28 November. Similar exposures were obtained for the 5 February. The minimum exposure for the six hour period was for the vertical surface orientated to the south with average $UVBE_{ery}$ exposures of 1.9 mJ $cm^{-2}$ for both dates.

### *4. CONCLUSION*

This paper has presented results on the spatial and temporal variations of the solar erythemal ultraviolet radiation for humans in a greenhouse. The method of a spectrum evaluator based on passive dosimeters was employed with a one hour exposure period. Meters do not possess sufficient sensitivity to the erythemal UV in the UVA waveband for measurement of these irradiances in a greenhouse. Spectroradiometers may be employed for measurement of the ambient UV, however, these are expensive and impractical for measurement of the personal UV exposure over an object of study. The additional advantages of the spectrum evaluator are that it allows the evaluation of the spectrum and calculation of the erythemal UV for any orientation at multiple sites simultaneously and that it takes into account any shading by plants or greenhouse structural elements that occurs throughout the exposure period.

The maximum in erythemal UV for humans in the greenhouse does not occur at noon as expected when the outside irradiances are at their highest. Instead it occurs in the morning on the eastern side of the greenhouse and in the afternoon on the western side. The erythemal UV remains relatively uniform from 09:00 to 15:00 EST in the centre of the greenhouse whereas any humans on the eastern and western sides experience variations as high as 78% during this period. Estimation of human UV exposure in a greenhouse can be derived from the data collected in this project. For example, the exposure to the shoulder can be calculated using the exposure to a horizontal plane. From the results presented, the cumulative erythemal exposure to the shoulder, in a standing posture, over a six hour period was 5 mJ $cm^{-2}$ or 0.25 MED. However workers spending all day in the greenhouse should still undertake UV preventative measures to reduce the UV exposure as previous research has established the damaging role of repetitive suberythemal UV exposures.

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Table 1 - Orientations of the spectrum evaluators where the inclination angle in degrees is relative to the horizontal and the azimuth angle in degrees is relative to north along with the evaluated erythemal and total UVA exposures for the 12 November, 1996.

| Orientation | Inclination angle | Azimuth angle | $UVBE_{ery}$ $\mu W\ cm^{-2}$ | Total UVA $mW\ cm^{-2}$ |
|---|---|---|---|---|
| T | 0 | - | 0.23 | 0.69 |
| N | 90 | 0 | 0.14 | 0.40 |
| E | 90 | 90 | 0.13 | 0.40 |
| S | 90 | 180 | 0.12 | 0.35 |
| W | 90 | 270 | 0.16 | 0.48 |

Table 2 - Details of exposure times, solar zenith angles and cloud cover.

| Exposure date and time | Solar zenith angle (degrees) | Cloud cover at 9:00 EST (octa) | Cloud cover at 15:00 EST (octa) |
|---|---|---|---|
| 28 NOV 96 | | 0 | 5 |
| 9:00-10:00 EST | 30 | | |
| 11:30-12:30 EST | 10 | | |
| 14:00-15:00 EST | 39 | | |
| 5 FEB 97 | | 1 | 1 |
| 9:00-10:00 EST | 38 | | |
| 11:30-12:30 EST | 14 | | |
| 14:00-15:00 EST | 35 | | |

Table 3 - The ambient UVA irradiances on a horizontal plane in the greenhouse.

| Time (EST) | Ambient UVA (mW cm$^{-2}$) | | |
|---|---|---|---|
| | East side | Centre | West side |
| 9:00 | 2.2, 2.0, 2.2 | 1.0, 1.0, 0.8 | 1.0, 0.7, 1.0 |
| 12:00 | 1.1, 1.1, 1.3 | 1.4, 1.2, 1.2 | 1.1, 1.2, 1.2 |
| 15:00 | 0.8, 0.7, 0.7 | 0.7, 0.7, 0.7 | 1.3, 1.3, 1.5 |

Table 4 - Irradiances measured with the radiometers in the various wavebands outside the glasshouse on 12 November, 1996.

| | Time (EST) | |
|---|---|---|
| | 10:58 | 11:45 |
| Erythemal irradiance (MED $hr^{-1}$) | 3.3 | 4.0 |
| UVA irradiance (mW $cm^{-2}$) | 4.9 | 5.1 |
| Visible illumination (LUX) | 86000 | 113000 |

Table 5 - Evaluated irradiances for each orientation (T, N, E, S, W) at each site on 28 November, 1996.

| Time (EST) | Orientation | UVBE$_{ery}$ ($\mu$W cm$^{-2}$) | | |
|---|---|---|---|---|
| | | ES | C | WS |
| 09:00-10:00 | T | 0.29 | 0.22 | 0.20 |
| | N | 0.12 | 0.08 | 0.11 |
| | E | 0.29 | 0.16 | 0.14 |
| | S | 0.10 | 0.07 | 0.06 |
| | W | 0.09 | 0.08 | 0.09 |
| 11:30-12:30 | T | 0.23 | 0.24 | 0.22 |
| | N | 0.10 | 0.07 | 0.10 |
| | E | 0.10 | 0.08 | 0.08 |
| | S | 0.08 | 0.08 | 0.08 |
| | W | 0.11 | 0.11 | 0.11 |
| 14:00-15:00 | T | 0.18 | 0.18 | 0.32 |
| | N | 0.07 | 0.06 | 0.11 |
| | E | 0.07 | 0.06 | 0.09 |
| | S | 0.09 | 0.10 | 0.14 |
| | W | 0.16 | 0.17 | 0.29 |

Table 6 - The erythemal irradiances on a horizontal plane and the averages of the irradiances on a vertical plane for each time at each site on 5 February, 1997.

| Time (EST) | Site | $UVBE_{ery}$ ($\mu W\ cm^{-2}$) Horizontal | Vertical |
|---|---|---|---|
| 09:00-10:00 | ES | 0.29 | 0.15 |
| | C | 0.20 | 0.12 |
| | WS | 0.21 | 0.12 |
| 11:30-12:30 | ES | 0.23 | 0.10 |
| | C | 0.25 | 0.10 |
| | WS | 0.25 | 0.10 |
| 14:00-15:00 | ES | 0.18 | 0.09 |
| | C | 0.18 | 0.11 |
| | WS | 0.25 | 0.13 |

Table 7 - The irradiances measured outside the greenhouse.

| | 28 November 1996 | | | 5 February 1997 | | |
|---|---|---|---|---|---|---|
| | am | noon | pm | am | noon | pm |
| Erythemal (MED $hr^{-1}$) | 2.8 | 3.8 | 1.9 | 2.7 | 4.8 | 2.6 |
| UVA (mW $cm^{-2}$) | 4.4 | 5.1 | 3.5 | 4.8 | 6.0 | 4.0 |
| Visible (LUX) | 104200 | 111100 | 84150 | 113100 | 154250 | 87900 |

## FIGURE CAPTIONS

Figure 1 - Schematic of a plan of the greenhouse with the location of the sites for measuring the ambient UVA (x) and the sites for evaluating the biologically effective UV (ES, C and WS).

Figure 2 - The solar spectral irradiance (1) and filtered with the greenhouse glass only (2) and the shadecloth only (3).

Figure 3 - The variation over the day of the erythemal irradiances for the ES, C and WS sites inside the greenhouse on 28 November, 1996 on (a) a horizontal plane and (b) the average to the vertical surfaces.

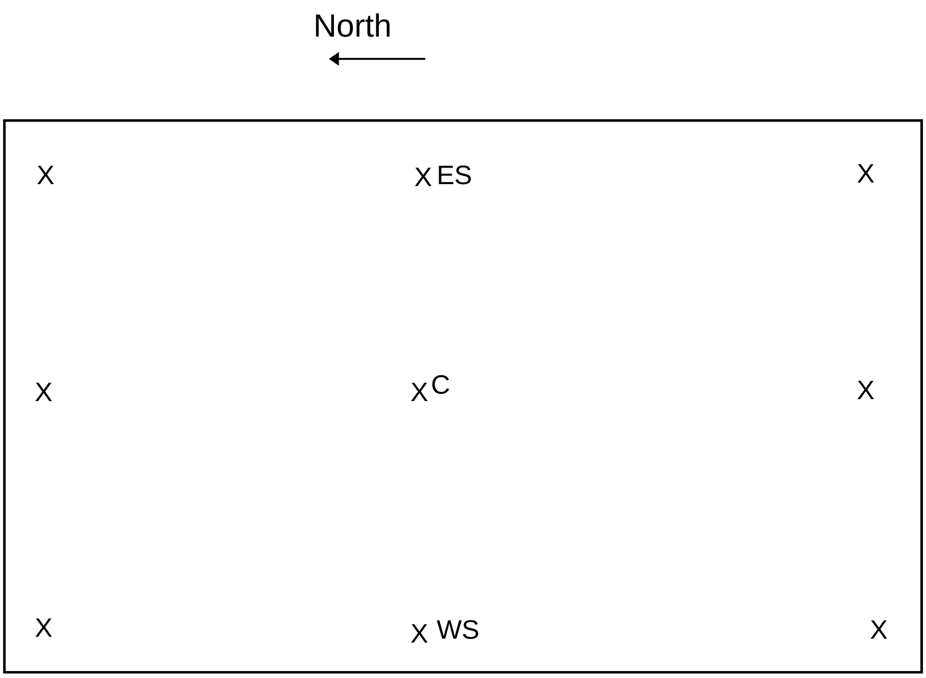



Figure 1

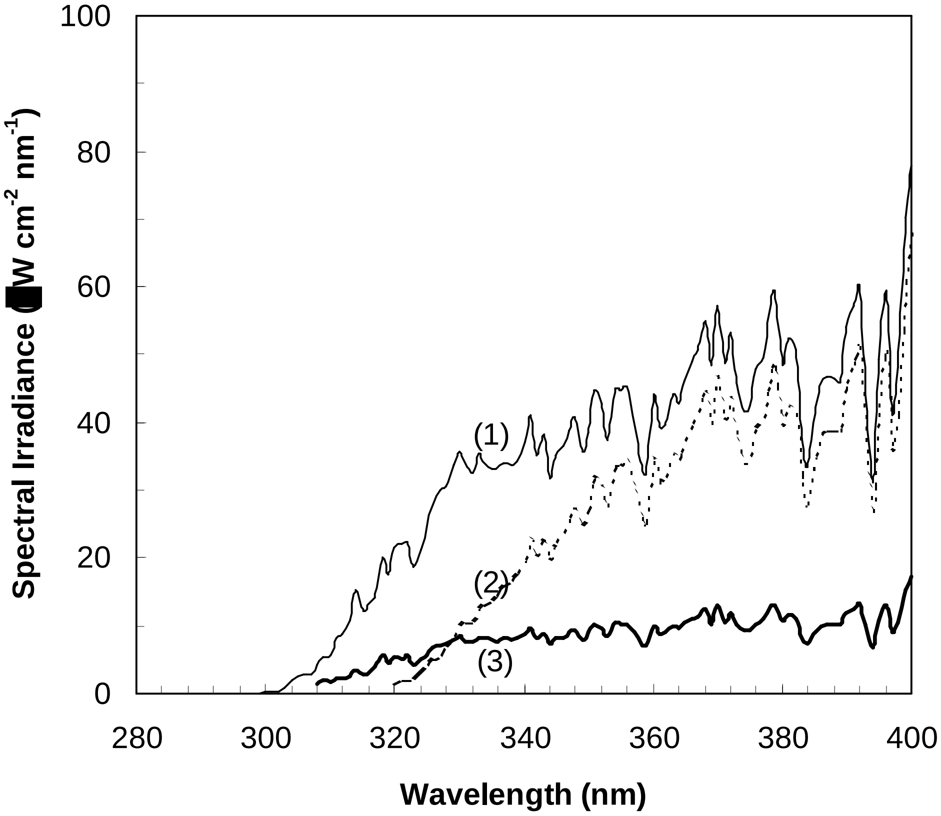
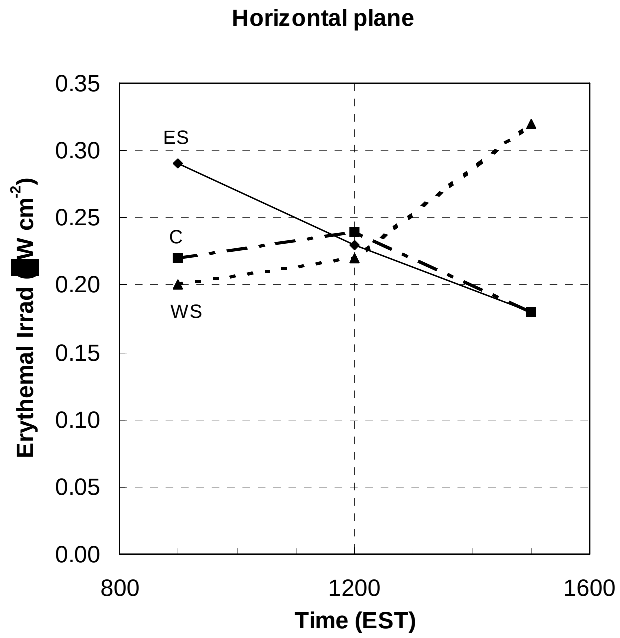

100
80
60
40
20
0
Spectral Irradiance ([redacted]W cm$^{-2}$ nm$^{-1}$)
(1)
(2)
(3)
280
300
320
340
360
380
400
Wavelength (nm)

Figure 2


Horizontal plane
0.35
0.30
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ES
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Erythemal Irrad (W cm-2)
800
1200
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Time (EST)

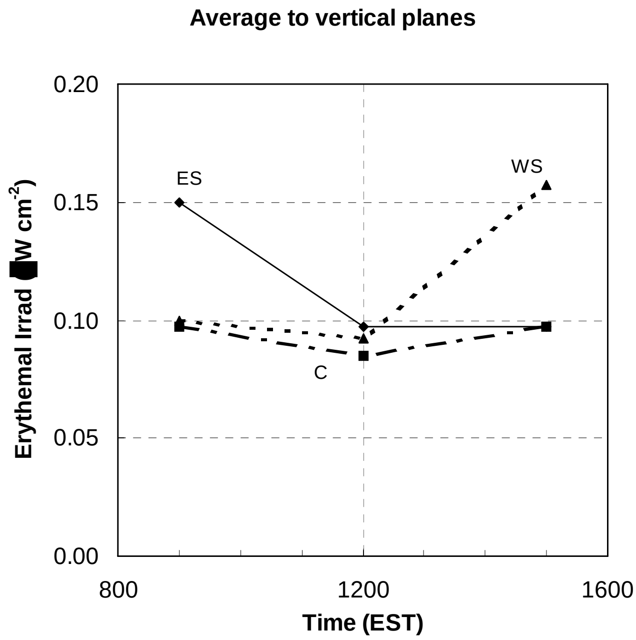
Average to vertical planes
0.20
0.15
0.10
0.05
0.00
ES
WS
C
Erythemal Irrad (W cm-2)
800
1200
1600
Time (EST)

Figure 3