HUMAN UVA EXPOSURES ESTIMATED FROM AMBIENT UVA MEASUREMENTS

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Short title: Human UVA Exposure

ABSTRACT

The methods presented in this paper allow for the estimation of human UVA exposure using measured UVA irradiance values. Using measured broadband UVA irradiances over the period of a year, it was estimated that for humans in an upright posture and not moving the head with respect to the body, the nose received 26.5% of the available ambient UVA radiation, whilst the shoulders and vertex of the head received 81% and 100% respectively of the available ambient UVA radiation. Measurement of the exposure ratios for a series of solar zenith angles between 90^o and 0^o will allow extension of this technique to other latitudes.

1. INTRODUCTION

It has been long believed that the majority of photolesions in human skin and eyes were due to UVB (280 to 320 nm) radiation. Recently, studies have suggested that high exposures to UVA (320 to 400 nm) will produce changes in human skin similar to those caused by long-term exposure to solar UVB radiation (Kligman and Gebre, 1991; Lavker and Kaidbey, 1997; Lowe et al., 1995; Seité et al., 1997; Bissett et al., 1992). Similarly, other researchers suggest that it would be unwise to dismiss the possibility that UVA is a major causative factor in the development of human malignant melanoma (Young, 1998).

Many studies have been conducted on the personal erythemal UV exposure to the human population (Kimlin et al., 1998a, Gies et al., 1995). These studies use erythema, or skin reddening 8 to 24 hours post UV exposure (Diffey, 1992), which has an action spectrum (CIE, 1987) weighted more heavily to the UVB rather than the UVA segment of the UV spectrum, as a basis for benchmarking skin damage.

Research by Kimlin and Parisi (1999) investigated the solar UV spectrum transmitted through window glass in automobiles, and found the UVA radiation levels within the vehicle were not reduced significantly by the glass. A further study by Parisi and Kimlin (2000) measured the broadband UVA irradiances inside various vehicles over the course of a year and found that UVA irradiances were detected inside the vehicle at all times during the year. The annual exposure to unfiltered solar UVA radiation by the British population has been estimated (Diffey, 1996). These projects highlighted the need for a method to estimate human UVA exposure during outdoor activities.

This paper presents a method to estimate the UVA exposure of humans using measured UVA irradiances. The technique presented in this paper will allow for expansion to future projects in the measurement of UVA personal exposures.

2. MATERIALS AND METHODS

2.1 Ambient UVA Irradiances

The ambient UVA irradiances in Toowoomba (27.5°S, 151.9°E, altitude 693 m), Queensland, Australia have been monitored using a permanently mounted outdoor UVA meter (model 501, Solar Light Co., Philadelphia, PA). The meter is located atop of a 4-storey building with an unobstructed field of view at the campus of the University of Southern Queensland (USQ). The UV meter records the UV data as a base integral over a 15 minute time period.

The outdoor UVA meter was calibrated in winter, in clear sky conditions against a calibrated spectroradiometer, with the UVA exposure, calculated using the following equation:

$$UVA = T\int_{320}^{400} S(\lambda)d\lambda \qquad \text{J.cm}^{-2} \qquad (1)$$

where S(λ) is the solar spectral irradiance in 1 nm increments and T is the exposure period. The calibration factor was subsequently applied to the entire measured UVA dataset presented in this paper. Another calibration was undertaken in December 2001 with the instrument's response varying only by 0.05%. Due to the small change in the calibration between summer and winter, a calibration was not done in spring and autumn. In February, a complete month of UVA data were not collected, therefore, the average over the days in that month for which data were collected was applied to that month.

The spectroradiometer used for calibrations in this research is a dual holographic grating (1200 lines/mm) monochromator (model DH10, Jobin Yvon Co., France) and a UV sensitive photomultiplier tube detector (model R212, Hamamatsu Co., Japan), temperature stabilised to 15.0 ± 0.5 ^{o}C, to measure the spectral irradiances in one nanometre steps. The input optics of the spectroradiometer are based on a 15 cm diameter integrating sphere (model OL IS 640, Optronics Laboratories, Orlando, USA) that is used to compensate for the poor cosine response of the monochromator.

The spectroradiometer was calibrated to a 250 W quartz tungsten halogen UV standard lamp before each set of measurements. This standard UV lamp has calibration traceable to the Australian UV standard housed at the CSIRO National Measurements Laboratory, Lindfield, Sydney, Australia. Before each set of measurements, wavelength calibration of the spectroradiometer was checked against the UV emission lines of a mercury vapour lamp. The wavelength of the monochromator was adjusted if the error exceeded 0.5 nm.

2.2 Anatomical Site UV Exposure Ratio

The anatomical UV exposure ratio is defined as the ratio of the UV exposure to a selected anatomical site compared to the ambient UV exposure on a horizontal plane and is expressed as a number between 0 and unity. The anatomical UV exposure ratio was measured using polysulphone film. Polysulphone film has been previously used to measure erythemal ultraviolet exposures (Diffey et al., 1979; Kimlin et al., 1998b; Kimlin and Parisi, 2000; Parisi et al., 2000). The polysulphone is not sensitive to wavelengths longer than 330 nm and no easy-to-use dosimeter materials are currently available for measurements in the UVA waveband. For example, the dosimeter based on 8-MOP (Diffey and Davis, 1978) also responds to UVB and the system of four different dosimeter materials for evaluating the UVA dose (Wong and Parisi, 1996) is not as easy-to-use as polysulphone. In this paper, the distribution of UVA radiation over a human will be estimated using exposure ratios determined with polysulphone dosimeters and it is assumed that the anatomical distribution of erythemal UV is the same as that for UVA. Although, the distribution of the UVA radiation may be different to the erythemal UV, the aim is to provide a first order approximation. The anatomical distribution of erythemal UV differs from that of the UVA radiation due to the differences in the relative percentage of diffuse eythemal UV compared to UVA. Over a year, at the latitude of this research, the percentage diffuse erythemal UV ranged from 23 to 59%, whereas the percentage diffuse UVA ranged from 17 to 31% (Parisi et al., 2001). The smallest difference between the diffuse UV in the two wavebands occurred at noon and was of the order of less than 20%. Consequently, the error introduced by employing polysulphone dosimeters to estimate the UVA anatomical distribution is estimated to be of the order of 20 to 30%.

The film was cast using equipment specially constructed at the University of Southern Queensland and the sheet was cut and mounted into 25 mm x 25 mm rigid plastic holders, each with a 1 cm^2 central aperture. The pre- and post- exposure optical absorbency of the polysulphone dosimeters at 330 nm was measured in a spectrophotometer (model UV-1601, Shimadzu Co., Kyoto, Japan). The polysulphone film was calibrated against an outdoor erythemal UV meter (Solar Light Co., Philadelphia, PA) in full sun conditions each season from approximately 07:00 Australian Eastern Standard Time (EST) to 12:00 EST. The erythemal UV meter was calibrated against the spectroradiometer described previously in this paper. During the calibration process, solar UV spectral scans were taken from large to small solar zenith angles and the erythemally weighted irradiances were multiplied by the time interval between scans to allow comparison of the resulting erythemal UV exposures with those from the erythemal UV meter. The error associated with polysulphone measurements is of the order of ± 10%.

Polysulphone dosimeters were deployed on the anatomical locations of manikin human forms to measure the exposure ratios as follows: vertex of head, nose, left and right ear, chin, left and right cheek, forehead, neck, left and right shoulders, left and right forearms, spine, sternum, left and right of the front and back of the thighs and shins. These manikins were placed on a rotating platform in an open, unshaded field at the USQ campus, using a technique as described elsewhere (Kimlin, et al., 1998a). The UV exposure ratios were measured in each of the four seasons of the year and linearly interpolated to calculate the exposure ratios for intermediate months (Kimlin et al, 1998a,b,c).

2.3 Distribution of the Annual Anatomical UVA Exposure

The anatomical distribution of annual UVA exposure for southeast Queensland was estimated using the following equation for each site (Rosenthal et al., 1991; Diffey, 1992; West et al., 1998; Moise et al., 1999):

$$UVA_{Annual} = \left(\sum_{m} \sum_{i} N(m).UVA(i).ER \right) \qquad J.cm^{-2} \qquad (2)$$

where *N(m)* is the number of days in the month, *m*, UVA(i) is the UVA exposure on a horizontal plane for each 15 minute period, *i*, of the day (as measured by the UVA broadband instrument), and *ER* is the anatomical UV exposure ratio for a particular site (as described in the previous section).

2.4 Human UVA Facial Exposure Distribution

The monthly anatomical UVA exposure as determined in the previous section for each particular facial site was used. The average monthly UVA exposures were bilinearly interpolated between each of the dosimeter sites over the entire facial region to draw a series of contour plots over a representative human facial image (Kimlin et al., 1998c, Downs et al., 2001). Analysis of the exposure ratio data and production of contour plots was handled using the *Interactive Data language (Research Systems, Inc., IDL version 5.4)* using a method described previously in Downs et al. (2001). This technique allows the visual representation of the estimated UVA exposure to the human facial region.

3. RESULTS

3.1 Ambient UVA Levels

The UVA irradiances per day as recorded on a horizontal plane in Toowoomba are shown in Figure 1. Day to day variations occurred in the collected data, due to clouds and other atmospheric processes. Nevertheless, in summer (December to February), the peak UVA exposure was 205 $J.cm^{-2}.day^{-1}$, while a minimum value of 19 $J.cm^{-2}.day^{-1}$ was recorded. In comparison, the data in McKenzie et al. (2001) for a clear day at Mauna Loa (19.5^{o}N) on March 12, 1998 gives a UVA exposure of 175 $J.cm^{-2}$.

3.2 Annual Anatomical UVA Exposure

After applying the daily UVA exposures averaged over each month and the anatomical UV exposure ratios, interpolated for each month, to equation (2), the daily UVA exposures averaged over each month for various anatomical locations were determined and are shown in Figure 2, with an associated error of 1 standard deviation of the monthly values. For the facial sites, the highest exposure location during the year was the forehead during the month of January (summer).

Figure 3 shows the annual UVA exposure to various anatomical sites for a person in an upright position whenever they are exposed to solar UVA radiation. Over the period of a year, the nose received 26.5% of the available ambient UVA radiation, whilst the shoulders and vertex of the head received 81% and 100% respectively of the available ambient radiation.

3.3 Human Facial UVA Exposure

The facial UVA exposure over the period of one year for each monthly interval using collected ambient UVA data is shown Figure 4. The presentation of the data using this method allows the visualization of the facial UVA "hotspots" over a period of one year. It can be seen that during the summer months of low solar zenith angles (December, January, February), the distribution of UVA dose over the face is predominately over the vertex of the head, rather than on the vertical sites of the face, such as the cheeks. Whilst in the winter months (June, July, August), the distribution of UVA is more towards the vertical sites of the face, such as the nose and eyes. This collected data suggests that UV protective devices which rely on the interception of UV for protection, such as hats, may provide more relative protection in the summer months than in the winter months for both the erythemal UV and UVA radiation.

4. DISCUSSION

The methods presented in the paper allowed for the estimation of the UVA exposure using measured UVA values. Measurement of the exposure ratios for a series of solar zenith angles between 90^o and 0^o will allow extension of this technique to other latitudes. Throughout this research the anatomical UV exposure ratios determined for erythemal UV were employed. This is due to no suitable easy-to-use UVA dosimeter being available for personal UV dosimetry. Future research on UVA distribution over the human form should investigate the development of a suitable UVA dosimeter.

Using measured broadband UVA exposures over the period of a year, it was estimated that the nose received 26.5% of the available ambient UVA radiation, whilst the right and left shoulders and vertex of the head received 81% and 100% respectively of the available ambient radiation. These values for the shoulders are particularly of concern as fashion trends in moderate to hot climates have led towards clothing which exposes more skin around the shoulder region, in particular for women. Unlike the face and arms, this area of the body may not be an area where broad-spectrum sunscreen is applied on a daily basis, therefore premature skin damage may be occurring in this part of the population due to this high UVA exposure. This paper highlights the need for more research into an effective, reliable, easy to use UVA dosimeter for personal UVA measurements.

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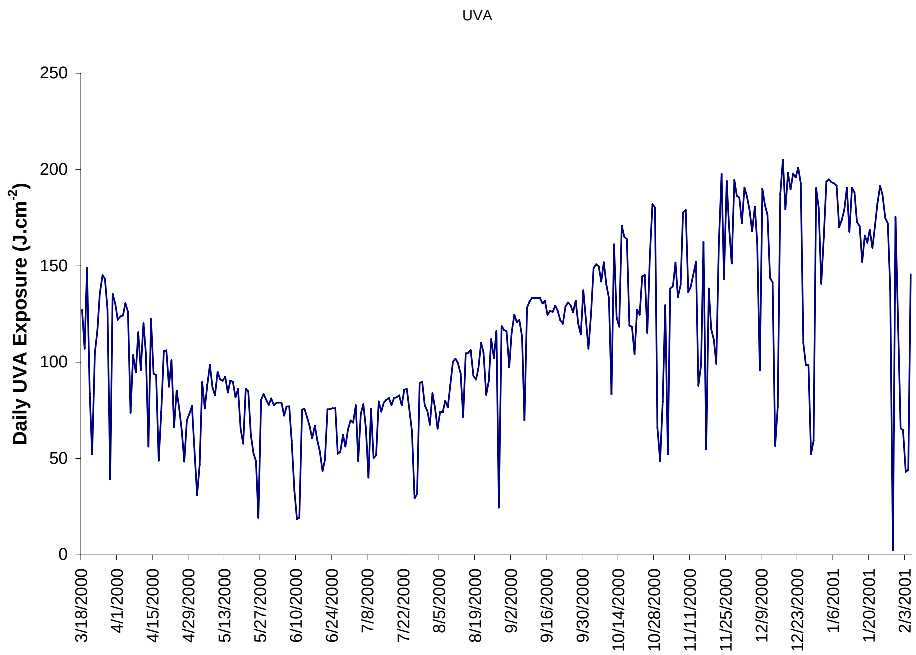
LIST OF FIGURES


UVA
Daily UVA Exposure (J.cm-2)
250
200
150
100
50
0
3/18/2000
4/1/2000
4/15/2000
4/29/2000
5/13/2000
5/27/2000
6/10/2000
6/24/2000
7/8/2000
7/22/2000
8/5/2000
8/19/2000
9/2/2000
9/16/2000
9/30/2000
10/14/2000
10/28/2000
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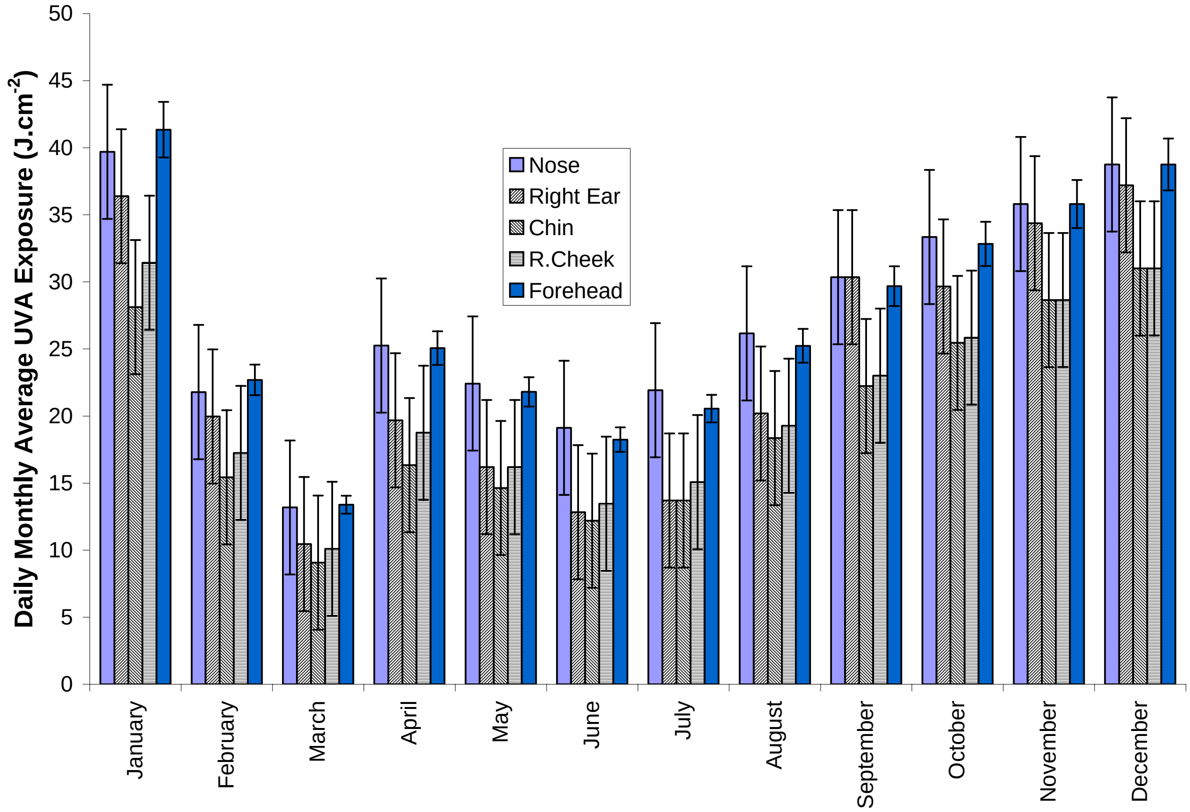
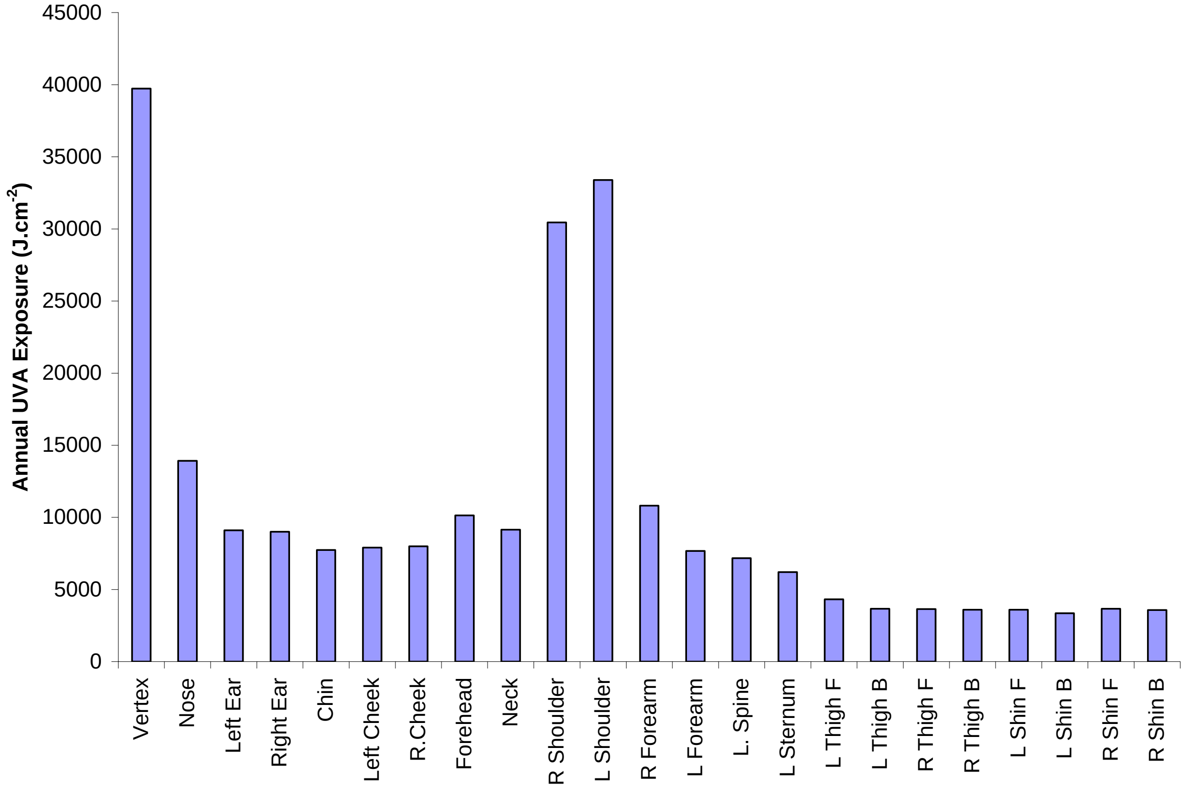
11/25/2000
12/9/2000
12/23/2000
1/6/2001
1/20/2001
2/3/2001

Figure 1



Daily Monthly Average UVA Exposure (J.cm-2)
0
5
10
15
20
25
30
35
40
45
50
Nose
Right Ear
Chin
R.Cheek
Forehead
January
February
March
April
May
June
July
August
September
October
November
December

Figure 2



Annual UVA Exposure (J.cm-2)
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Vertex
Nose
Left Ear
Right Ear
Chin
Left Cheek
R.Cheek
Forehead
Neck
R Shoulder
L Shoulder
R Forearm
L Forearm
L. Spine
L Sternum
L Thigh F
L Thigh B
R Thigh F
R Thigh B
L Shin F
L Shin B
R Shin F
R Shin B

Figure 3

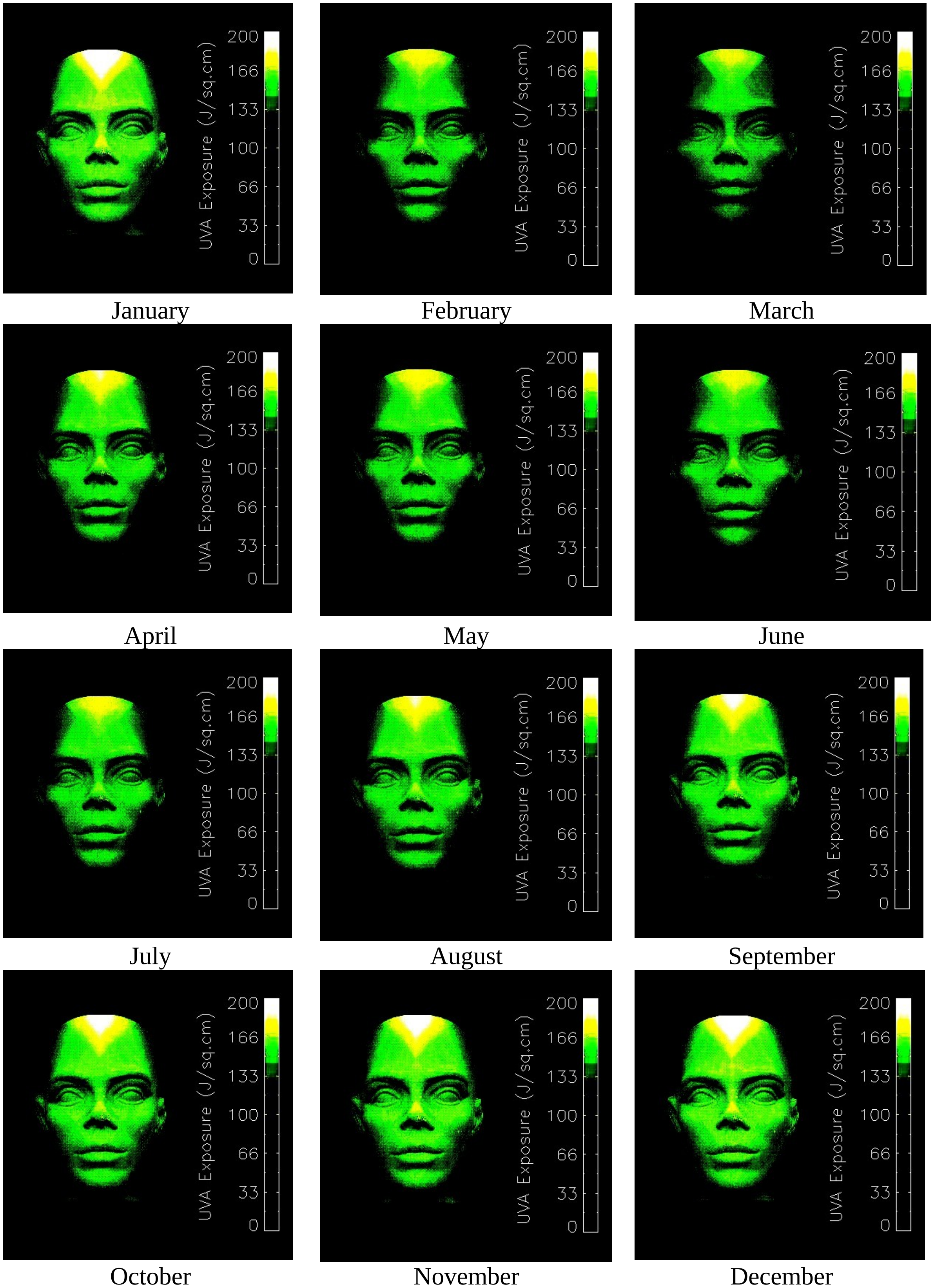

UVA Exposure (J/sq.cm)
200
166
133
100
66
33
0
January
February
March
April
May
June
July
August
September
October
November
December

Figure 4