MODELLING HUMAN FACIAL UV EXPOSURE

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ABSTRACT

There are strong links between exposure to UV radiation and both adverse health outcomes (eg. skin cancer, cataracts) and protective health outcomes (e.g. the production of vitamin D). The aim of our research is to develop methods of estimating cumulative UV exposure in a manner suitable for risk-factor epidemiology. We have developed a flexible computer model that determines UV exposure over the human facial region (utilising exposure ratios as determined by polysuphone dosimeters) for various solar zenith angles (SZA). By adjusting latitude and time of year, researchers can estimate cumulative facial UV exposure for particular geographical locations and time periods.

INTRODUCTION

The influence of ultraviolet (UV) radiation's causative role in human skin cancer, premature skin photo-aging and wrinkling and some eye disorders has been established[1]. On the other hand, UVB (280-320 nm) is also necessary for the production of vitamin D[2]. Vitamin D deficiency has been reported for a wide range of sites[3] [4], including south-east Queensland[5]. Measurement networks have been established in some countries for the monitoring of the terrestrial solar UV irradiances. However, few long-term datasets that are necessary for the analysis of trends exist. Consequently, models that incorporate the parameters influencing solar UV irradiances have been developed and employed[6] [7] [8].

These models predominantly calculate the ambient UV irradiances on a horizontal plane. UV dosimeters[9] have been employed for the evaluation of the exposure ratio (ER) or the fraction of the ambient UV exposures incident to specific human body sites[10]. This paper extends the previous research and incorporates the measured exposure ratios of human facial sites for different solar zenith angles (SZA) in a model for calculating the horizontal plane UV to evaluate the UV exposure to these sites.

MATERIALS AND METHODS

Modelling UV Irradiance

Pro2uv is a developed software package that calculates the global (direct and diffuse) UV exposure received on a flat surface at sea level based on the semi-empirical UV irradiance model of Green et al[7]. The software is designed to generate a single data file of integrated irradiances (exposures) taking into account ozone thickness (Dobson units), cloud cover (okta's), year, month, day, hour and latitude. Atmospheric air thickness (elevation above sea level) and particulate thickness are considered to be constant in this instance[7]. The generated data file lists the hourly UV exposure totals for the diffuse, direct and global components of received radiation. Also listed by the output file are the hourly global exposures weighted by each of the erythemal[11], actinic[12] and vitamin D[13] action spectra. Erythemal exposures are converted to MED (minimal erythemal dose) assuming 200 Jm^{-2} in a MED[14]. The software employs a semi-empirical ozone model to evaluate the ozone concentration for any location on Earth[15]. The effect of cloud, and variations in the Earth-Sun distance that influence the extra-terrestrial spectral irradiance are accounted for by factors formulated by Josefsson[16].

The solar zenith angle is calculated in 15-minute increments for the specified location. The position of the Sun to within 1^o, is based on an algorithm presented in the Astronomical Almanac and is implemented by the software as described by Michalsky[17]. Each integrated irradiance is progressively summed as the program executes; based on a trapezoidal integral approximation. Although there are more sophisticated numerical integration techniques available, the trapezoidal approximation is the fastest and easiest method to employ in this case whereby integrations are progressive and recorded to a data file for different times. The integration of the diffuse, direct and global irradiances are evaluated in 15-minute steps in accordance with the calculated position of the Sun.

Measurement of Exposure Ratios

The exposure ratios to specific facial sites were measured employing polysulphone dosimeters[10]. These were deployed on specific facial sites of a manikin headform and additionally on a horizontal plane on the vertex of the headform. Single dosimeters were placed at each of the: forehead; nose; left and right cheek; left and right ear; chin; front of the neck; left and right shoulders; and upper chest. Figure 1 shows the dosimeter locations over the headform. Each polysulphone dosimeter was made from thin film polysulphone secured to a small holder (similar to a slide holder) with a central aperture of around 1 cm^2. The polysulphone was constructed at the University of Southern Queensland in a manner described previously[18]. The absorbency at 330 nm of the polysulphone dosimeter was measured in four different locations through the dosimeter aperture before and after exposure to solar UV radiation in a spectrophotometer (Shimadzu Co., Kyoto, Japan). The average change in absorbency measured across the dosimeter aperture was calibrated to the erythemal exposure using the function[19]:

$$D = K(a+a^2+9a^3) \quad (1)$$

where *D* is the erythemal exposure, *a* is the change in absorbency and *K* is a calibration constant

All experimental measurements were performed in Toowoomba (27.5^{o}S 151.9^{o}E, alt 693m), however the measurement of exposure ratios would be valid to a first approximation in any other region of the world for similar solar zenith angles and surface UV albedo. To simulate the random movement of a person standing upright, the exposed headform was placed on a rotary mechanism, rotating approximately two times every minute. Similar manikin rotation mechanisms, rotating with sufficient speed with respect to the movement of the Sun have been used in the past to simulate the random movement of human subjects(18) (20) in an upright position.

The measured UV exposure to each facial site was divided by the UV exposure measured on the vertex of the head and expressed as a value from zero to unity. The UV exposure to the face is dependent primarily on the: irradiances on a horizontal plane; SZA; cloud cover; surrounding environment; ground albedo; angle of head; hat and sunscreen protection(18). In this research, it was assumed that no hat or sunscreen was employed and that the head was in an upright position. The UV albedo of the grass ground surface was less than 5%. The exposure ratios were measured for each 10^o increment of solar zenith angle between 70^o and 30^o during various dates and times in September 2000. Measurements were conducted in an open, unshaded location and over 30 meters from the nearest buildings and other sources of shade. The influence of cloud was not considered and relatively cloud free measurement days were selected; the highest level of cloud cover recorded was less than 2 okta of alto-cumulus cloud.

Evaluating Human Facial Exposure

Each exposure ratio for a particular solar zenith angle range was used to weight the UV exposure predicted by the model for a horizontal plane to the appropriate facial site. An integrated exposure over a given spring day in Toowoomba was used to achieve this by progressively summing the exposures calculated for each 10^o SZA step and weighting them with the respective exposure ratios for each facial site. This process involves dividing the desired exposure time interval into 10^o steps and finding the appropriate time at which each step interval occurs. The closest time interval can be found using the *Pro2uv* software that lists the solar zenith angle at every 15-minute integration step. The error associated with rounding the time interval to the nearest 15 minutes was on average, no more than 1^o in solar zenith angle. This small error only slightly affects the weighting of the necessary exposure ratio, that will at most assign on average less than 10% of the predicted horizontal UV exposure to the next highest or lowest facial exposure ratio for the days tested. Each integrated facial exposure for each 10^o increment was summed at every dosimeter location to produce cumulative facial exposures for different times of the day for each facial site. The cumulative exposures were bilinearly interpolated between each of the dosimeter sites over the entire facial region to draw a series of contour plots. Analysis of the exposure ratio data and production of contour plots was handled using the *Interactive Data language (Research Systems, Inc., IDL version 5.3.1)*

RESULTS AND DISCUSSION

Erythemal Exposure at Ground Level

The daily erythemal exposures predicted by the model for a horizontal plane were compared for the two days of 1 January (summer) and 1 July (winter) 2000. Two surface maps for cloud free days, normalised to sea level are shown for Queensland, Australia in Figure 2. Using the *Pro2uv* software, the cumulative daily erythemal exposure was calculated at a number of latitudes to generate a grid of data points. The erythemal exposure at sea level was interpolated (using *IDL* and bilinear interpolation) to produce both maps showing total MED per day. The effect of latitude and time of year are evident in this comparison.

Measured Exposure Ratios

Figure 3 shows the exposure ratios interpolated over the face for the SZA ranges between 30^o and 70^o for clear sky conditions. A higher ratio of exposure to more vertical regions of the face for large solar zenith angles was found. When the Sun is higher in the sky (smaller solar zenith angles), the majority of the UV radiation is incident from a higher angle, therefore most of the exposure is to the top of the head and nose rather than the cheeks and chin. The average distribution of exposures measured over the ranges from 30^o to 70^o are consistent with previous results obtained for facial exposures normalised to the vertex of the head (Table 1).

Integrated Daily Facial Exposures

The modelled cumulative facial UV exposure for 15th of September 2000 is shown in Figure 4 for the cloud free case. Lower solar altitudes in spring, restrict the exposure ratio series to solar zenith angles between 70^o and 30^o resulting in more atmospheric scattering than received in summer when the Sun is higher in the sky. A similar cumulative exposure plot produced for a typical day in summer would have a much higher level of exposure and a wider range of facial exposure distributions due to the wider range of solar zenith angles on a summer's day.

CONCLUSION

The developed software and integration with a database of exposure ratios for different SZA developed in this research allows the determination of the UV exposure to the human facial region. By using this software, cumulative UV exposures to the facial region may be determined. The software will allow those interested in UV-related disorders to estimate cumulative exposures based on the life chart approach (assessing location and amount of outdoor activity during an individual’s life). In addition, for those interested in assessing vitamin D deficiency, the model allows the calculation of minimal outdoor activity required for vitamin D production at any latitude and month of year. Limitations of the current model are: the narrow range of solar zenith angles; possible atmospheric irregularities (actual cloud conditions, aerosol and ozone distributions); and changes in the physical environment (changing surface albedo, shade and surroundings). Future versions of this model will include more solar zenith angles and the examination of the effect of cloud, human activity, body posture and clothing on UV exposure.

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Table1: Comparison of measured distribution of exposure to the human facial region.

Facial Location	**This research September 2000***	**Kimlin et al[18]**	**Diffey et al[20]**	**Gies et al[21]**	**Holman et al[22]**
Head vertex	1	1	1	1	1
Forehead	0.58	0.43	0.54 - 0.62		
Nose	0.63	0.57	0.61 - 0.67		
Chin	0.46	0.12	0.30 - 0.38		
Left Cheek	0.44	0.21	0.46-0.50	0.17 - 0.30	0.15 - 0.47
Right Cheek	0.41	0.37	0.46-0.50	0.17 - 0.30	0.15 - 0.47
Left Ear	0.33	0.25			
Right Ear	0.24	0.26			
Neck	0.27	0.28			
Left Shoulder	0.70	0.80	0.83 - 0.91	0.89 - 0.99	0.66 - 0.70
Right Shoulder	0.62	0.80	0.83 - 0.91	0.89 - 0.99	0.66 - 0.70
Upper Chest	0.56				

* Average exposure ratio measured across the range 70^{o} to 30^{o}

Figure Captions

Figure 1: Dosimeter locations (+) on the manikin headform.

Figure 2: Horizontal plane erythemal exposures normalised to sea level for summer (a) and winter (b) over Queensland.

Figure 3: Measured exposure ratios interpolated over the face for different SZA's

Figure 4: Cumulative facial exposure calculated using the *Pro2uv* horizontal plane model and changing solar zenith angle exposure ratio measurements for 15 September 2000.

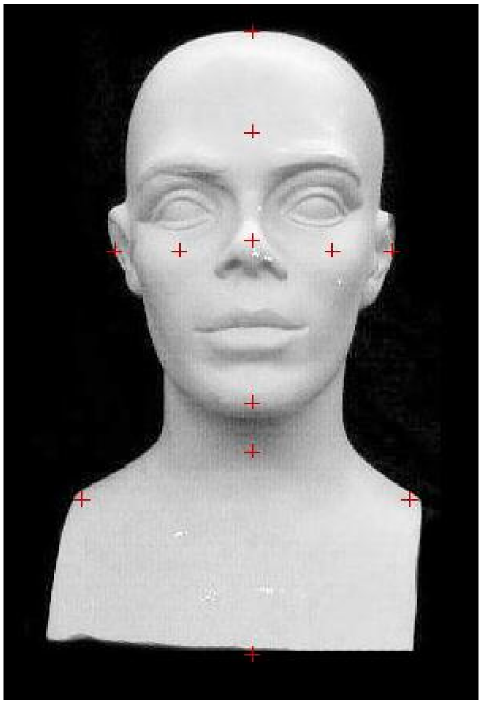
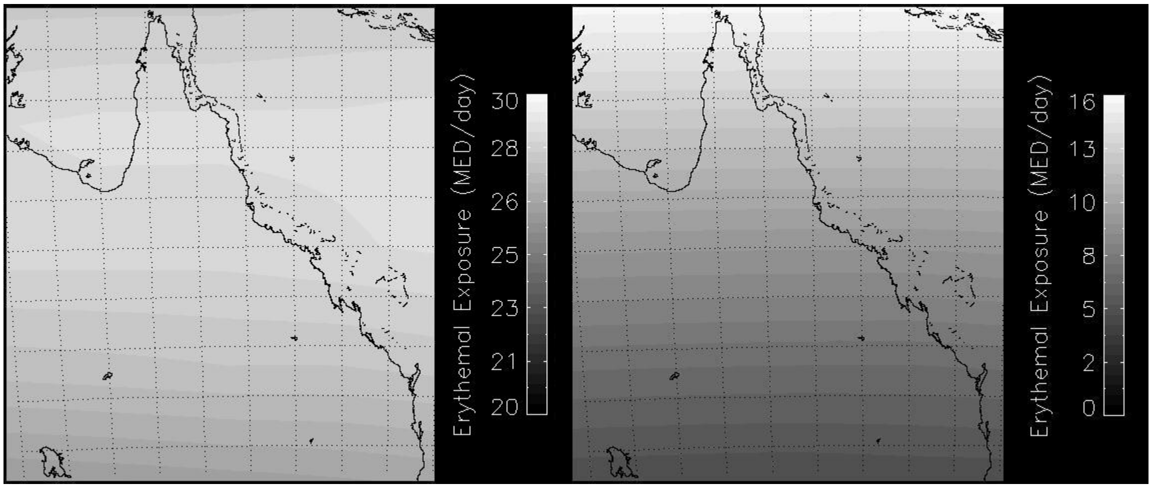
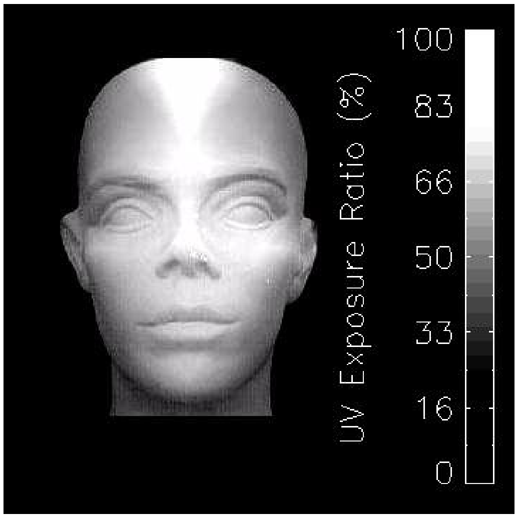


Figure 1

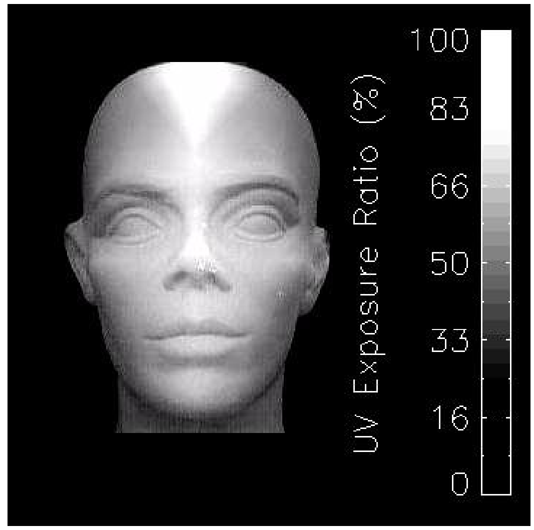

Erythemal Exposure (MED/day)
30
28
26
25
23
21
20
Erythemal Exposure (MED/day)
16
13
10
8
5
2
0

(a) (b)

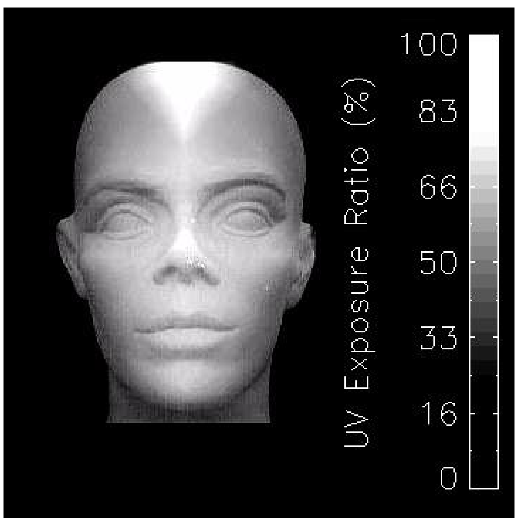
Figure 2



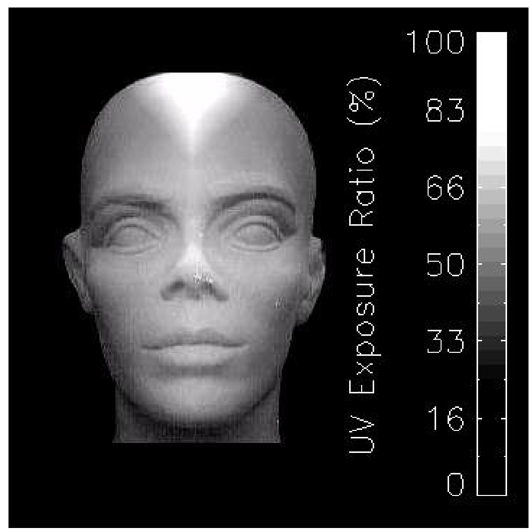
(a) SZA 70°-60°



(b) SZA 60°-50°



(c) SZA 50°-40°



(d) SZA 40°-30°

Figure 3

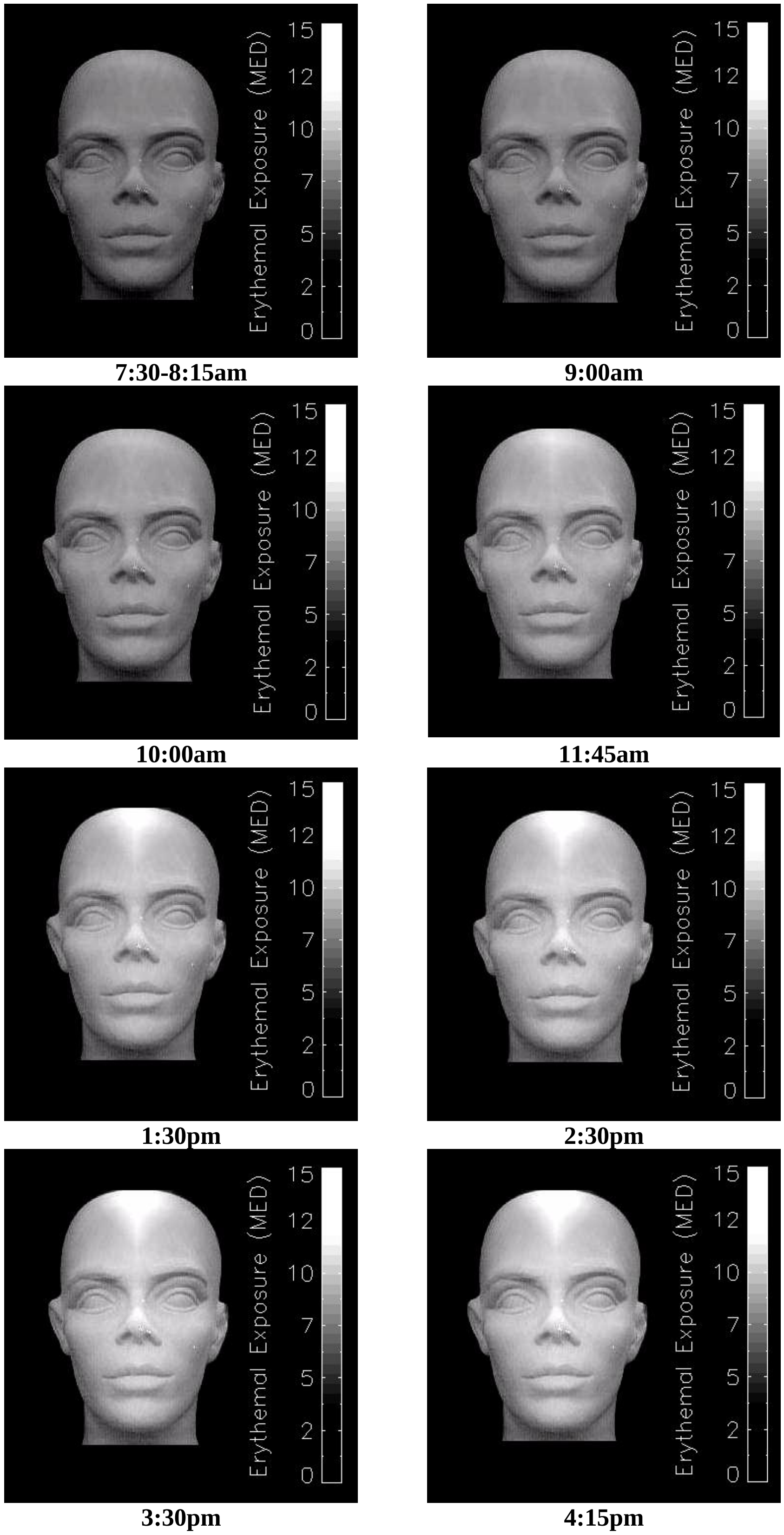

Erythemal Exposure (MED)
0 2 5 7 10 12 15
7:30-8:15am
9:00am
10:00am
11:45am
1:30pm
2:30pm
3:30pm
4:15pm

Figure 4